

**United States Military Academy  
West Point, New York 10996**

**DENYING ACCESS TO AN AREA AND  
CONTROLLING ENEMY MOVEMENT:  
ALTERNATIVES TO LAND MINES**

**DEPT. OF SYSTEMS ENGINEERING  
TECHNICAL REPORT**

**By Second Lieutenants**

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Land Mines

  
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ALTERNATIVES TO LAND MINES**

**A TECHNICAL REPORT OF THE  
DEPARTMENT OF SYSTEMS  
ENGINEERING**

**A CAPSTONE DESIGN EXPERIENCE  
FOR SYSTEMS ENGINEERING MAJORS  
ACADEMIC TERM 98-2**

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Project sponsored by the U.S. Army Armament Research, Development  
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## EXECUTIVE SUMMARY

The Area Denial design group of Stephen E. Douglas, Michael T. Golden, Franklin B. Scherra, Jr., Bryan J. Wiley, Mike Talbot, and Eric R. Swenson, has designed a system that will limit access to an area and constrain the movement of the enemy forces. Several types of land mines are in use today that fall under the anti-tank or anti-personnel categories. These mines can be employed in many different manners. Some require aerial dispersal while others have to be deployed manually. Land mines are an effective means to delay, fix, disrupt, deny, turn, or destroy enemy forces in combat. However, unrecovered conventional land mines pose a threat because they remain armed after the conflict ends. Currently, several nations are proposing to ban anti-personnel land mines that do not self-destruct or can not be command detonated. We assume the political pressure against land mines will eventually encompass both anti-personnel and anti-tank mines. The mounting political pressure against land mines has forced the United States to look for alternatives to deny enemy force's access to specific areas. The objective of our group was to provide alternative area denial systems to replace the conventional land mine. Our most promising alternative deals with the Intelligent Wide Area Munitions (IWAM) because of the extensive work that has already been done on that system.

We used an iterative systems engineering design process to create plausible alternative solutions to the problem of area denial. Our work on alternatives involved brain writing and brain storming sessions. We developed several alternatives; after screening them over several constraints we eliminated a chemical and electrical alternative. We then analyzed the remaining alternatives in depth. We developed models to evaluate and compare the effectiveness of the alternatives. One model was a simulation involving the Carlton lethality function for modeling the killing effectiveness of each particular alternative system. By running the alternatives through 4000 iterations of the simulation, we generated information on the effectiveness of each alternative. We assumed an alternative is effective if it denies two or more enemy vehicles out of a total of fourteen enemy vehicles. We considered a successful area denial system to be one where 80% of the 4000 iterations resulted in denials. Our results indicate that the IWAM and robotic vehicle alternatives, where an object is physically on the ground and contains a deterrent, yield a higher probability of success than the other alternatives. The large quantity of

conventional mines or artillery rounds needed to achieve similar success makes mines and indirect fire rounds cost ineffective. However, the usefulness and cost effectiveness of indirect fire rounds can be increased through target designation. Not only do conventional mines have high material costs in the quantities required, they require additional manpower costs to employ and remove. This cost would be similar when using conventional indirect fire rounds. An EMP alternative also achieved a high percentage of denials with a small number of rounds. The far-reaching effects of one EMP round expand the effective radius and increase the cost effectiveness of the EMP alternative. Although EMP does not have a physical deterrent effect on the battlefield, it is a silent and non-lethal combat multiplier. It is a promising alternative that we recommend for further development and future use in the Army. Until it can be fielded though, we believe the IWAM or a robotic alternative is best.

## INTRODUCTION

Conventional land mines indiscriminately injure or kill thousands of non-combatants world-wide each year.<sup>1</sup> Organized military units use land mines to fortify and protect forts, bridges, key terrain, and land. Guerrillas and terrorists use land mines to achieve political goals. Often times these land mines are not recovered, so they remain armed in areas that are no longer combat zones. Unfortunately, these conventional mines cause many injuries and claim many lives, thus creating an international movement to ban the use of land mines.<sup>1</sup>

The main function of the conventional land mine is area denial. Area denial is a major concern in the Army today. Since the United States government is considering the support of the proposed international ban on land mines, the US Army is exploring ideas for an effective alternative to the land mine. Our client, Mr. Larry Ostuni of Picatinny Arsenal has the goal to provide the US Army with effective alternatives that will fulfill and even extend the current functions of land mines. An area denial system involves the control of territory so as to turn, disrupt, delay, and/or fix the enemy movement. The system must be an effective and politically acceptable replacement to land mines. Since we expect conventional landmines may be banned by the year 2000, the Army may need to field an alternative within the next few years.

## FORMULATION OF ALTERNATIVES

### Problem Definition

#### Needs Analysis

Our design group of Mike Golden, Frank Scherra, BJ Wiley, Mike Talbot, Eric Swenson, and Steve Douglas worked on the strategic military problem of area denial. Our client is Mr. Larry Ostuni, who works at ARDEC located at Picatinny Arsenal, NJ. The client's primitive need is to provide a means to deny access of enemy personnel, aerial and land vehicles, and equipment to an area. From this we derived the effective need: **to provide a safe and effective**

means to control the position and movement of enemy forces.

Table I lists the key stakeholders along with their respective interests:

**Table I.** Key stakeholders and their respective interests

<b>Stakeholder</b>	<b>Objective</b>
<b>Picatinny Arsenal</b>	Provide an effective means to control the position and movement of the enemy forces so they can help the Army develop a viable area denial system.
<b>DOD, Army</b>	Effective means of area denial. Minimize cost. Incorporate in plan the following aspects: maintenance, shelf life, disposal cost, Mean Time Between Failures, deter counter measures, technology (ease of use).
<b>Politicians</b>	Appease constituents. Minimize cost Look out for health of non-combatants in places where mines may be located. Provide a good defense.
<b>Public</b>	Ensure soldier as well as noncombatant safety. No long term effects and cost Provide for a good defense.
<b>Allied Countries</b>	Create technology that can be integrated into their existing systems. Minimize cost and develop a system that is legal.
<b>Producer</b>	Make money by getting the contract to make the new system. Minimize the MTBF.
<b>Army Unit Leaders</b>	Maximize the speed of employment and removal. Provide detection and area denial and safety. Keep up in technology and training needs.
<b>Army Engineers</b>	Create a system that is emplacement and removal friendly. Develop a plan for transportation to units. Enforce a training policy. Deter counter measures.
<b>US Soldiers</b>	Safety of the soldier. A system that can identify friendly or foe and provide adequate protection. Minimize training time it takes to become proficient.

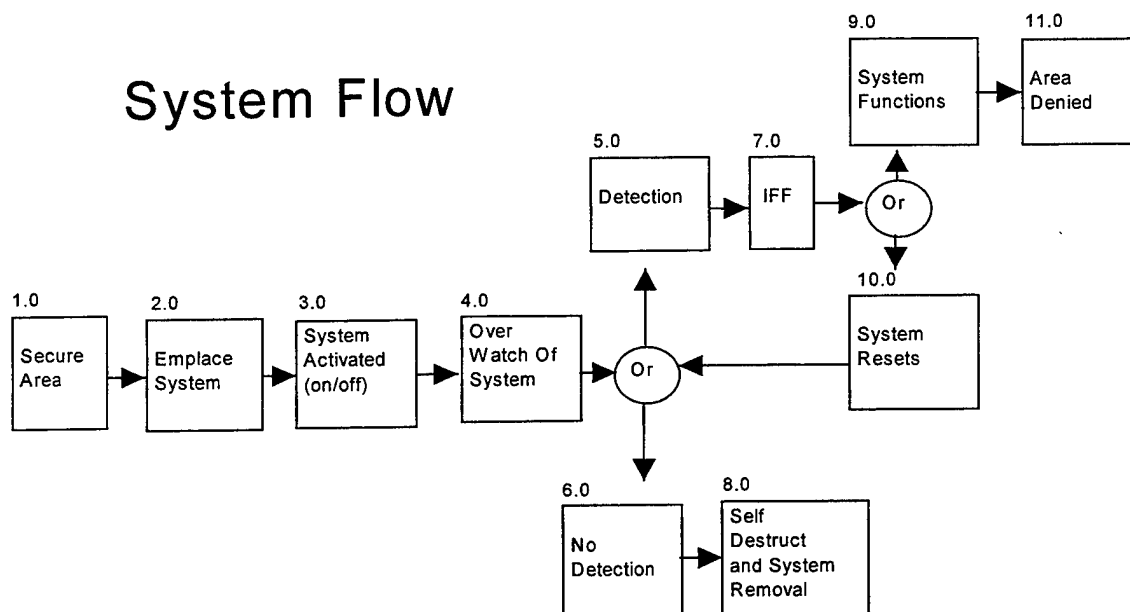
### **Scope and Bound of the Problem**

Table II shows the inputs and outputs of an area denial system at each stage in the system life cycle. Inputs comprise two types: controllable and uncontrollable. Outputs are labeled as either intended or by-products.

**Table II.** Input-Output Model for an area denial system

<b>Life cycle</b>	<b>Controllable</b>	<b>Uncontrollable</b>	<b>Intended</b>	<b>By-Product</b>
<b>Design</b>	Budget Methods Used Info/Surveys NATO/Army Specifications	Public Opinion	Area Denial Safe and Reliable System	Costly Making New FMs
<b>Production</b>	Labor Materials Reusable Part(s)	Raw Materials Labor Relations Changing Technology Safety Requirements	High Quality Reliable System Durable	Defects Jobs High Cost Old Equipment Health Hazards
<b>Distribution</b>	Delivery Costs Storage Distribution to Units	Demand Shipping Damage	Efficiency Low Transportation Costs	Back-Orders Shipping Delays Trash/Packaging
<b>Operation</b>	Area of Operation Arming/Disarming Training Propaganda	Public Opinion Environment/Weather Restrictions on AO	To deny the enemy from an area through attrition or forcing a change in the desired route.	Waste Environmental, Health Hazards Inaccuracies/Failures
<b>Retirement</b>	Upgradable Recyclable materials	Technology Changes	Recyclable No Long Term Environmental Effects	High Disposal Costs

A functional decomposition is useful in explaining the area denial process. Figure 1 shows a flow diagram that traces major functions of an area denial system from the initial stage through the identification stage and finally to the decision stage where the system either denies the area, resets, or is removed.



**Figure 1.** Functional Decomposition of an area denial system

## System Requirements

We developed requirements to which the new systems must adhere. These requirements include a method to inactivate or activate the system, encryption to protect the communication to the system, identify friend or foe (IFF) to prevent fratricide, and a self-destruct mechanism to keep the Army from having to remove the system and to prevent enemy tampering.

The EMP alternative will not have to adhere to all of the above requirements depending on how it is employed, and the satellite-based system similarly will not need to meet all of these requirements because of its trajectory. New alternatives are also constrained by the attitude of the politicians. We are trying to find an alternative to landmines that will control an area in a more deliberate manner. A large part of appeasing the political demand is making the system controllable by a man in the loop and modularized in order to facilitate easier upgrades. The new system must be able to be fielded within the next ten years, so we will most likely have to draw from available or near-term technology.

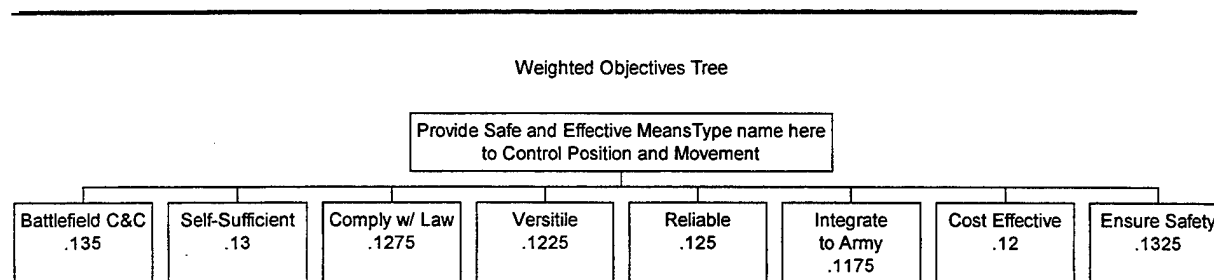
## Value System Design

### Objectives and Goals

We developed several objectives that stemmed from the effective need. We compared the alternative area denial systems according to how well they met each specific objective. This was measured in terms of criteria. We generated numerical values for each criterion with each alternative that were used to identify the strongest alternative.

We devised a scale to help rank the top-level objectives, using the House of Quality (see Appendix C). The house of quality allowed us to evaluate the objectives and criteria to see how each interacted with the others. We evaluated the strengths and weaknesses of the interaction effects between the objective and criteria and also between different criteria. The House of Quality provided estimates of the relative importance of the objectives. We gave the most important objective an 8% increase over the other objectives and the rest of the objectives fell in rank order with 6%, 4%, 2%, -2%, -4%, -6%, -8. The weighted objective tree is shown in Table III. The complete objective layout is outlined in Appendix C.

**Table III.** Weighted objective tree for an area denial system



## Criteria

We developed criteria or measures of effectiveness that could be used to measure how well each alternative met each objective. These are summarized in Table IV.



**Table IV.** Measures of effectiveness for analyzing the alternatives

	Criteria
<b>Cost to deny area</b>	Operational \$ to deny and Area 10 km x 10 km
<b>Expected time to field</b>	The time in years to field the alternative, starting at present
<b>Mean time between failures</b>	The average time in hours between system failures
<b>Size of footprint</b>	Size in square km.
<b>Life Span</b>	Life span of the alternative in years: at $\geq 95\%$ reliability
<b>Probability a unit is detected</b>	Fraction of enemy units detected
<b>Probability a unit is stopped</b>	Fraction of enemy units stopped
<b>Penetration percent</b>	Given the enemy is stopped, what percentage of the area on average did he penetrate
<b>Number of enemy killed</b>	How many enemy kills were recorded per attack

### **Engineering Problem Statement**

An agency of the United States government (the US Department of State Political-Military Affairs Bureau) is considering restricting the use of land mines and possibly eliminating them from our arsenals in the future. To assist mission effectiveness, the US Army must be able to deny enemy forces entry into specified areas. Essentially the Army is looking for a safe and effective means to control the position and movement of the enemy forces.

A problem with the use of conventional land mines for area denial is that they are indiscriminate killers that may not be safely removed or detonated once they are no longer needed. Months and even years after a conflict, conventional mines may be left behind, allowing someone or something to trigger them. Over one hundred million land mines lie in over one third of the countries in the world.<sup>1</sup>

The goal of our client is to develop alternatives that can replace and possibly outperform conventional land mines. They must be able to turn, disrupt, delay, and fix an enemy's movement. In addition to the new system's military role, it must also be legally and politically acceptable.

### **Area Denial Mechanisms**

To better understand the concept of area denial we divided the function into three sub-functions: identification, delivery, and destruction. There are several methods that apply to each function. It is the combination of the one method per sub-function that details how the alternative will perform.

## Identification System

### *Satellite*

Using this observation method, 10 satellites will be deployed for every 40 kilometer-wide strip of land to be observed. This will allow satellite coverage above the area 24 hours a day. The satellites will have the capability to “see through” the clouds and to “see” at night. They will be deployed at an altitude of 600-700 km and have a viewing angle capability of about 45 degrees. Each satellite will have a cost of about \$50M, similar to the cost of a fighter jet. At any given time, each satellite will be able to view a footprint area of 40 km by 40 km. The satellite will be able to download this image to a mobile ground station that is within 2000 km of the satellite every 10 minutes. This means that the enemy has at most 10 minutes before they are detected by this alternative. The satellites will always be in place, so the set up time will be the time to get the mobile ground unit in place. The information from the satellites will be sent to a fire direct center (FDC) through the mobile ground station, and indirect fire will deter the enemy from the denied area. These satellites have a life expectancy of 7 years with at least 95% reliability, and they can “see” so well that they are accurate to within 10 meters and can distinguish objects such as vehicle license plates. It will take two to three years before this system can be put to use by the Army. Almost all of the technology is existing, but we must compile the best aspects of current satellites to create these military satellites.<sup>13</sup>

### *IWAM System-*

With the IWAM system, the commander can customize the size of the denied area by adding more IWAM's. Each IWAM is capable of observing a radius of 600 meters until destroyed. They can be hand or Volcano employed. They have a useful life of 30 days after being employed unless unused and recovered. The network of IWAM's will detect vehicles up to 600 meters out with its geoseismic sensors and engage vehicles over five tons within 100 meters. The round takes 3-4 seconds after launch and achieves a mobility kill. The IWAM can also send the information on the vehicles back to a remote control unit, which will in turn relay that information to an FDC. The FDC can initiate fire to engage the target, denying the area. The enemy vehicles have at most 1 minute

until detected after entering the 600-meter radius. Any target approaching within 15 meters of the IWAM will be engaged, and if disturbed, the IWAM will explode its round in place.<sup>14</sup>

#### *UAV System-*

UAV's can observe a 2 square kilometer without ever leaving any of the area uncovered for more than 30 seconds. The UAV will relay the visual information to a monitor that provides locations for indirect fires to the FDC. Each UAV can last 5 years with at least 95% reliability. The "Global Hawk" has a flight endurance of 42 hours, a load capacity of about 2,000 lbs., and can fly at altitudes up to 65,000 feet. The cost per UAV is around \$10M based on the "Darkstar", a UAV similar to the "Global Hawk".<sup>15</sup>

#### *Robotic System-*

The research on this alternative reveals that its use is very dependent on terrain, but in some situations, it can provide "eyes" on an area to be denied that may have otherwise placed human lives in jeopardy. Each robotic vehicle will cost around ten thousand dollars. After being driven into place by remote control, the vehicle will employ a camera for observation that depends on line of sight with existing terrain. This will probably average out to about 200 meters of coverage forward of each vehicle. Several vehicles will be placed in parallel and series to cover the area. It will take approximately 30 seconds for the monitored activity to be observed by the operational control unit (OCU) which will relay the information to the FDC. The robotic vehicles can also designate the enemy targets.<sup>16</sup>

#### Delivery System

Delivery consists of the receipt of the target, the processing of the request, and launching the method of destruction. There are several delivery methods: multiply launch rocket system (MLRS), 155mm howitzer, and the self-contained delivery. Self-contained delivery is the most complex system. Essentially, the delivery and detonation systems are combined into one compact munition. The munition is remote operated and may have a self-contained identification system that enables it to work anonymously. The MLRS is similar to the 155mm howitzer in that they both receive a call for fire from a fire direction center and process the data. Once the

data is verified and processed for use, the team launches the desired munitions at the target.

### Denial Mechanism

Once the round has been launched, it will perform based on the detonation method contained within the round. There are several destruction methods: electromagnetic pulse, high explosive 155mm howitzer rounds, family of scatterable mines (FASCAM), the IWAM high explosive shape charge, the M26 high explosive warhead for the MLRS and laser weapons on satellites.

## **Synthesis of Alternatives**

### **Development of Alternatives**

In order to develop alternatives to the land mine, our group performed brainstorming sessions, culminating in a brainwriting session. The ideas ranged from the use of existing technology to the development of new technology. We tried not to limit the ideas we produced in order to generate a wide variety of different possibilities. We later eliminated impossible or extremely unreasonable alternatives, and retained plausible alternatives for comparison and examination. The alternatives are significantly different and appear to fulfill most of the current functions of conventional land mines. In what follows, we describe each of the alternatives.

### **Alternatives**

#### **1. Robotic Sensor & Attack Vehicle Alternative**

This alternative requires the following technology and equipment: robotic vehicles that can emplace themselves and camouflage themselves, video cameras, GPS, laser ranging, real-time communication link from the robotic vehicle to the monitor station, an indirect fire center, acoustic and seismic sensors, a man-in-the-loop, and weapons that can be transported by the robotic vehicle.

A group of robotic vehicles, such as the SARGE or HUMVEE, that can be programmed to operate independently or remotely controlled will be sent to occupy an area.<sup>2</sup> They will have the capability to camouflage themselves or emplace themselves at the programmed or selected location. With a set of real time video cameras for navigation, soldiers located miles away will help place the vehicles. They will have on-board GPS and an additional video monitor to send

location and target information. This will also aid in visual identification of targets. The GPS will be used to facilitate navigation to the programmed location while a video and laser range finder will give the position of enemy targets. The robotic vehicles will have limited firing capabilities along with a self-destruct function and proximity weapon to prevent capture or tampering. The vehicles will dig themselves in or camouflage themselves and wait for their seismic and acoustic sensors to let them know that there is presence in the denied area. When activated by an intruder, they will "stand up" and either attack as programmed or examine the intruder through the use of video letting the man-in-the-loop make the decision. If this system is operated with a man-in-the-loop then the operator will have the capability to override the robotic vehicle. These vehicles can choose to engage or send a signal to an automatic indirect fire center that will hit the target they are designating. These vehicles will be placed on "safe" and return to their home location on command. They will be reusable, and all of the technology on them will be upgradable.

The range that the robotic vehicle can operate is several miles. This is based on the cross-country range of the SARGE. The vehicle has two way communication capabilities in order to send information regarding location, enemy, and enemy locations. In addition to communication, the SARGE is able to take panoramic pictures for further intelligence and surveillance purposes. This technology is already in use on the SARGE, and another version of the Hum-Vee. These two options run on conventional fuels. If another type of fuel or power were used, the vehicle's ability to maneuver and the range would vary. Depending on the mission, the fuel source should be fairly compact and lightweight to help the vehicle remain inconspicuous. A rechargeable power source may be an option. The cost for one SARGE with equipment is about \$25,000. This option requires the Yamaha Breeze as a foundation and the rest of the auxiliary equipment would be mounted on top of the frame.<sup>2</sup>

## **2. Big Bad Brother in the Sky Alternative-Satellites**

This alternative requires the following technology and equipment: satellites with the capability to observe an area and transmit real-time images and locations of intruders, communication link from the satellite to the monitor station, and possibly an indirect fire center. In addition, a laser weapon on the satellite that can be effective in killing armored vehicles on earth, a man-in-the-loop, and all of the requirements of one of the other alternatives to supplement this alternative in times of inclement weather if the satellite is unable to see through clouds or dust.

In this alternative, a system of satellites will observe the specific denied area. There will be sufficient satellites so that a satellite will always cover the denied area(s). Weather and cloud cover may inhibit the system from operating properly. The satellite system will have the capability to relay real-time information on the location of intruders in the denied area to include location and an aerial view of the intruder(s). The satellite will have the capability to engage the target from space using a laser weapon. It will either engage as dictated by prior programming or it will allow a man-in-the-loop to override the system and attack on the ground through the use of an indirect fire center. The man-in-the-loop will, for all practical purposes, be a security guard that makes decisions from the information provided on his real-time monitor. For support when clouds or other adverse weather conditions obscure the ground, robotic vehicles, UAVs, or WAMs may supplement this alternative.

In order to use this alternative, high-resolution satellite imagery is needed. Several commercial satellites equipped with this technology will be produced in the next few years. The US satellites that have just been deployed within the last year or will be deployed within the next year that use high-resolution imagery include: SIS, Eyeglass, and Worldview. The Russians have had this technology with the KVR-1000 since 1992.<sup>3</sup> Despite this new technology, further developments must be made to allow real time links to this imagery because this currently doesn't exist.

### **3. Chemical**

This alternative requires the following technology and equipment: IWAM's with the capability to detect seismic and acoustic disturbances, the capability to store a chemical without any type of significant decay, an attribute that would allow the chemical to stick to whatever it is attacking, and command activation and detonation capabilities.

In this alternative, a mine-type device will emit a chemical that will deter entrance to an area. It will initiate a reaction that will "eat" enough oxygen to cause enemy vehicle engines to cease working and also may cause enemy personnel to lose consciousness. Using the same idea as the IWAM, the mine would disperse the chemical. The mine would have the same seismic and acoustic capabilities to detect the enemy. When the mine detects an enemy soldier or enemy vehicle, it will emit the chemical compound.

The chemical will have a determined life span. Depending on the need of the force that deploys the device, the life span will dictate when friendly forces could reoccupy the denied area. This chemical will deplete oxygen levels; therefore, it will reduce the effectiveness of both light

and mechanized forces.

The focus of this device is to stop enemy vehicles. The engines of most military vehicles, friendly and enemy, are internal combustion engines. An internal combustion engine uses a sensitive combination of fuel and oxygen to propel the engine.<sup>4</sup> A chemical that will deplete the amount of oxygen surrounding the vehicle will disrupt the balance of the air and fuel combination, causing the engine to fail and the vehicle to stop.

The effective area or footprint that this chemical can cover will vary with the users need. The cost of the device and the chemical will also dictate the doctrine behind the use of the chemical alternative. This alternative is a medium range system. The Army will not emplace this system close to friendly lines since the chemical range will have a confidence interval associated with it. United States forces could also deploy it as a long-range area denial tool; however, the range of this device depends on the delivery mechanism.

#### **4. Electromagnetic Pulse (EMP)**

This alternative requires the following technology and equipment: deliverable round for EMP, laser or some other form of target designation, EMP technology, possibly an indirect fire center or aircraft for delivery, and potentially an EMP generator with remote control to emplace in the denied area.

Electromagnetic pulse (EMP) weapons are a plausible means of area denial. Current research in EMP technology is not only focusing on high altitude strike weapons, but it is also being considered for use by ground forces. EMP has many advantages over land mines. Recent tests of EMP simulators conducted on animals concluded that there were no adverse reactions to the pulses.<sup>5</sup> The IEEE United States Activities Board feels that chronic exposure to EMP simulator fields is unlikely to have any effect on human health or the environment. EMP technology is essentially non-lethal technology that can disable an enemy without the loss of life. EMP is still being tested for potential long-term effects. EMP generators could be strategically placed on the battlefield so as to disable any enemy aircraft, vehicles, or vessels. The electromagnetic pulse would essentially destroy navigational devices, electronic ignitions, etc. The pulse destroys electrical equipment and renders communication ineffective. The EMP device "disables any vehicle [trucks, missiles, and aircraft] dependent on electrical circuits to operate."<sup>6</sup> A remote controlled EMP generator that the Army could transport with minimal effort would potentially be a silent non lethal combat multiplier. The EMP generator would disable and delay the enemy from completing its mission.

This alternative has several potential emplacement methods. The first is to use a remote deployment method such as an unmanned vehicle that would identify a target as friendly or hostile. It could then be activated. Another deployment method is to deliver the EMP device in a 155mm artillery round directly on the enemy. Given the enemy is within range, a properly placed round would effectively reduce combat effectiveness and ability to move since the EMP would destroy enemy electronics. Picatinny Arsenal is currently working on integrating EMP technology into small arms rounds.<sup>7</sup> One advantage of a small-arms round is that it can precisely disable a lead vehicle in a column of vehicles.

The footprint for this alternative is dependent on the desired effect. EMP technology is currently being integrated to fit into intercontinental ballistic missiles. The size and range of this application are much larger than for a small-arms delivery. The most practical application is applying this technology to artillery rounds that will have maximum range of approximately 20 miles.

#### **5. Angel of Death--UAV's**

This alternative requires the following technology and equipment: UAV's with the capability to hover or equipped with video cameras that allow the image to appear as if the UAV were stationary. Also, this alternative requires GPS, laser ranging, real-time communication link from UAV to monitor station, a man-in-the-loop, an indirect fire center, and weapons that the UAV can transport.

The altitude of flight determines the footprint of the UAV. We envision the UAV flying no higher than one kilometer and having a footprint of two kilometers by two kilometers.

For this alternative, the Army will employ UAV's to observe the denied area. They will have video, GPS, and laser ranging capabilities that will allow them to "know" their own location and send the intruder's location along with a real-time image of the intruder. This information will be transferred to a monitor station where a "security guard" will receive and react to the given information. This man-in-the-loop, "security guard," will have access to indirect fire with which he can engage the intruder(s). The UAV's themselves can hold various weapons that they will release or fire on command. They will be loaded with weapons based on the force that they are expected to deter. These UAV's will be able to hover over the ground on the opposite side of the denied area as the indirect fire center to avoid being struck by the rounds. They will also have cameras with the ability to look at an area as if it were stationary even though the UAV is moving.



The cost of this alternative could be substantial. UAV's are currently in the research and development stage. There are several existing prototypes. For area denial purposes, the Army needs a UAV that can fly for extended periods without refueling, fly long distances, and carry surveillance equipment and limited amounts of weapons. One such UAV is the Dark Star, a work of Lockheed Martin and Boeing. The Dark Star has an endurance of eight hours, a payload of 1,000 lb., an altitude capacity of 45,000 ft., and a cost of \$10M per UAV.<sup>8</sup> Dark Star is fifteen feet in length with a wingspan of sixty-five feet, a body diameter of twelve feet and a weight of 8,900 lb.<sup>9</sup>

#### **6. Network of Destruction--IWAM's**

This alternative requires the following technology and equipment: IWAM's, GPS, Laser ranging, real-time communication link from the IWAM's to the monitor station, an indirect fire center, acoustic and seismic sensors, a man-in-the-loop, and a weapon for the IWAM.

In this alternative, the Army would employ a network of WAM's that can communicate with each other and a monitor center. The WAM's will have GPS and laser ranging capabilities along with seismic and acoustic sensors. They will activate when the sensors show an enemy to be present. They can operate autonomously according to a programmed operation or they can be commanded by a monitor. They will have weapons of their own like the current WAM's, but after they engage the enemy, they will remain an active part of the information network in the denied area. They will track the intruder and IFF based on the seismic and acoustic readings. When they decide to attack or are commanded to engage, they will fire their round. The target information can also be sent to an indirect fire center from which WAM rounds can be fired. The system can designate the rounds by use of the laser that is used to determine the range. The WAM's will have a proximity sensor to prevent the enemy from tampering with or destroying the WAM.

This alternative, unlike most of the other alternatives, is already available. The IWAM is now in the initial stages of production at Textron.<sup>10</sup>

#### **7. Shock of Death-Electricity**

This alternative requires the following technology and equipment: electrified concertina wire, charged high-voltage nodes, a remote control, and a man-in-the-loop to control it. This alternative will be mainly aimed at the personnel on the ground.

This alternative creates several deterrents on the battlefield. The Army will have an

electrified concertina wire fence to deny personnel. It will form an obstacle on the battlefield that will have to be disabled or moved around. When the fences make contact with an individual who is trying to cross it or cut through it, a high voltage current will disable him. It will have a remote control to activate it in the key times when it is needed for area denial.

The human body does not respond well to electricity. Once the fence is touched the personnel will be unable to let go of the voltage source. A strong shock will occur if contact is less than one heart period. Fibrillation followed by unconsciousness can occur if contact is longer than one heart period.<sup>11</sup>

Commercial electrical fences are currently used in livestock control. We would want to build on these systems in order to make them more deadly. Currently, KIWI Fence manufactures an AC Energizer System. The power source requirement is generally 110V-120V AC or 23V-240V AC, with an output of 12 joules.<sup>12</sup> This alternative will have very significant power requirements. For that reason the fence will remain off until the man in the loop turns it on presumably when the enemy is in the area.

### Feasibility Screening

We evaluated each alternative over several important constraints: cost, safety, humanity, failure rate, radius of kill, environmental concerns, technology available, and research available. The following feasibility matrix illustrates how each alternative fared.

**Table V. Feasibility Screening Matrix**

Alternative	Cost	Safe	Humane	Failure Rate	Radius of Kill	Env. Concerns	Tech. Available	Research Available	Go/NoGo
Electricity	High	No	No	High	Zero	Yes	No	Little	No Go
Chemical	High	No	No	High	Low	Yes	No	Little	No Go
EMP	Med	Yes	Yes	Variable	High	No	Yes	Little	Go
Satellite	Med	Yes	Yes	Low	High	No	Yes	Yes	Go
Remote Sensors	Low	Yes	Yes	Not Known	Low	Little	Yes	Little	Go
UAV	High	Yes	Yes	High	High	No	Yes	Yes	Go
IWAM	Med	Yes	Yes	Moderate	Low	No	Yes	Yes	Go

### **Alternatives Screened Out**

We ultimately ruled out the electric fence alternative because we felt that it did not meet some of our screening criteria. The electric fence would entail a bulky time-consuming emplacement, which would be permanent. This time-consuming, permanent emplacement was not what we envisioned as practical in the rapidly changing battlefield of the future. The fence poses environmental concerns in the form of fires. Safety of our forces is also an issue because high voltage electricity is always dangerous. The radius of kill would be zero because one would have to be right on top of it to get "zapped." Satisfying the power requirements of the system would be expensive and the power supply would be bulky. Most importantly the probability of failure of this system would be high. Possible failures could occur by accidental grounding of the system, severing a power wire, rain, moist conditions, etc. This alternative is not ready for use. If technological advances could reduce the probabilities of these failures, then this alternative could be a useful tool on the battlefield. Perhaps the stopping mechanism could be in the form of heat, rather than electric shock (like a super "flash bulb").

The chemical alternative is not the best alternative in terms of public opinion toward the use of chemicals on the battlefield. Wind, temperature, and weather on the battlefield greatly affect the deployment and effect of chemicals. Chemical weapons on the battlefield often hinder the commander's ability to reoccupy an area in which chemicals were deployed. Likewise, our chemical alternative will naturally have a low appeal to the public, which would be necessary to fund the technological advances necessary to field it. The chemical alternative may pose environmental concerns in the form of effects on plant life and habitats around the areas it is employed. Safety is also an issue as it pertains to emplacement by friendly forces. The radius of kill is directly related to weather conditions. Most importantly the probability of failure of this system could be high. The deployment system would also be a difficult project. It would have to include some type of sensor and relay that would have to know how to adjust the firing mechanism to account for weather, ground troops, and armored vehicles.

## **ANALYSIS OF ALTERNATIVES**

### **Systems Modeling and Analysis**

In order to compare the alternatives, we identified criteria to measure each alternative. We established the criteria to provide a quantitative means to compare many different aspects of the alternatives and determine which alternative is most effective in each of the aspects. These criteria are called measures of effectiveness. The measures of effectiveness we used to compare the alternatives are listed below.

- 1) Cost to deny 1 square kilometers --how much it will cost the Army in money, man-hours, and resources to deny 1 square kilometers.
- 2) Expected Denial Rate - Percentage of iterations of a simulation that resulted in a denial. A denial is achieved if two of fourteen enemy entities are killed. Either a catastrophic kill or a mobility kill achieves a kill.
- 3) Expected casualty rate in breaching the system--the expected number of enemy casualties that the system will cause from the time the enemy enters the denied area until it retreats or moves around it.
- 4) Expected time to breach the system--how long it will take the enemy to move through or around the system.
- 5) Expected effective life of the system--how long the system will remain in the desired area and delay the enemy.
- 6) Mean Time Between Failures (MTBF)--an average time that the system is reliable and before it malfunctions.
- 7) Range and footprint of the system--how far the Army can employ the system from a control center and the amount of area the system will cover.
- 8) Technology and time to field into the Army--how much new technology is required to develop the system, the reusability capabilities of the system, and how long it takes to distribute the system to the Army.
- 9) Time to employ--how long it takes to set-up the system in order to defend an area.

## **Modeling of Alternatives**

### Alternative Analysis

We ran a model on the different alternatives to evaluate the effectiveness of the different alternative simulations. Delivery angles determine the footprint shape. For simplicity, we assumed that the footprint or the area of destruction is circular. In addition, when firing artillery, the guns in an entire battery will each fire at least one round. Therefore, at least six rounds per fire mission. The probabilities of hit for each munition were based on the Carlton function. Essentially, the Carlton function allows us to predict the probability of hit for distances between the minimum and maximum lethal radius' of the systems.<sup>17</sup> Enemy units are deemed combat ineffective when the strength of the enemy is reduced below a specified level. The specified level depends on the mission and training of the enemy unit.

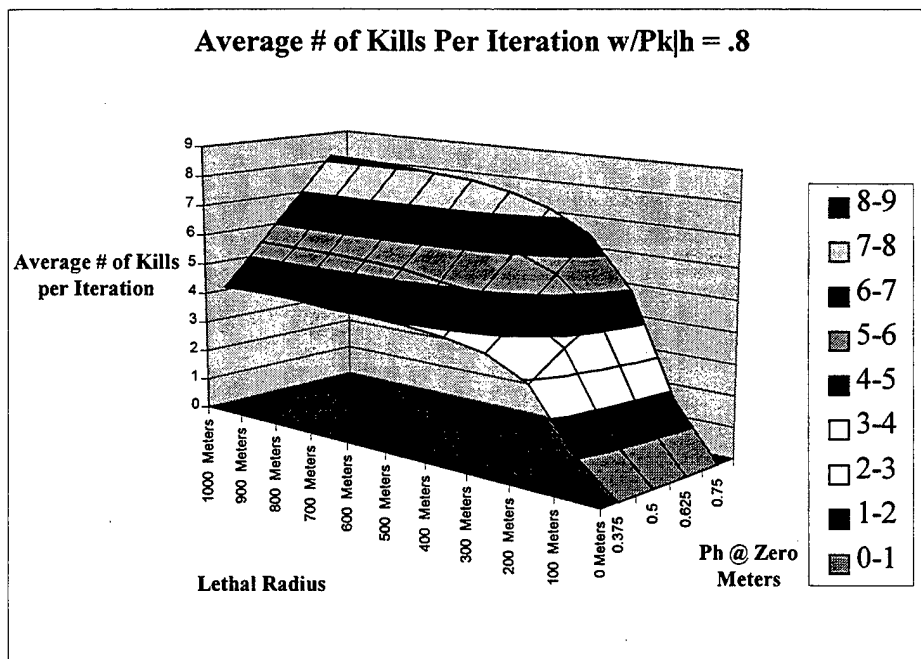
The probability of hit on a heavy armored vehicle that receives a direct hit from a 155mm HE round (one meter for center) is 97%. Normally a direct hit of high explosive rounds on a tank will destroy the vehicle; however, we took into account many of the factors that reduce the artillery reliability in this measure. Weather, wind, terrain, and equipment deviation (barrel temp, powder variations) will reduce reliability. In addition, the maximum miss distance for a kill is 35 meters with a probability of kill of 10%. This measure also takes into account that at 35 meters fragments may hit the vehicle, but they may not cause a mobility kill. The probability of incapacitation for a soldier in the open given a 155mm-howitzer rounds lands one-meter from the soldier is assumed to be 99%. The maximum range for incapacitation is assumed to be 35 meters. At this range the probability of incapacitation is assumed to be 10%.<sup>18</sup>

The simulation model uses Visual Basic® Modules in an Excel spreadsheet. It accepted several input parameters. After entering the input parameters which included: probability of hit at zero meters, the probability of hit the lethal radius, the probability of kill given hit, number of enemy entities, the number of kills to achieve a denial, and the number of rounds or mines available, we ran the model and gathered data on our measures of effectiveness. Some of our measures of effectiveness were: probability of stopping a unit, and rounds or systems required to accomplish denials 80% of the time. Our goal was to achieve a denial 80% of the time over 4000 runs with each alternative. We assumed that a denial would be accomplished after two targets were eliminated. There were fourteen enemy targets in our model.

Since each alternative is unique, the model inputs necessary to run each alternative are different. We ran the simulation for EMP, conventional mines,

conventional artillery, and IWAM. We assumed a constant 1km x 1km denial area. For simplicity we neglected that minefields are employed in depth.

We used three-dimensional surface plots to illustrate the effect that changes on the major input parameters had on the average number of kills. An example of a surface plot output of the EMP alternative where the probability of kill given hit is .8, is shown in Figure 1 below. More surface plots are available in Appendix F.



**Figure 1**

### Research Based Alternative Analysis

Criteria modeling only allowed assessment of several of the criteria. We assessed our remaining criteria on research based data. The data we collected was put into a raw data matrix. In addition to the data below, which only shows the observation component for each alternative, there will also be a cost due to type of round and delivery method for each alternative.

The following raw data matrix shows the data we used.

Measure/Alternative	IWAM	Satellites	Robotics	UAV
Cost to deny (10x10km)	10,000	500 Million	1 Million	600 Million
Lifespan at 95% reliability	2 years	7 years	2 years	5 years
Footprint sq. km.	1 km each	40 km	2 km	500 km
Time till operational	Now (0)	3 years	1 year	4 years

\*This is based on using fifty satellites, ten robotic vehicles with replacements, and 250 UAV's with replacements. Also, the Satellite alternative covers a 40-km band around the globe. To cover the suggested 10x10-km region suggested above requires the same cost and assets as the 40-km band around the globe.

The following matrix shows the cost-time characteristics of the alternatives. The cost refers to the cost to deny ten square kilometers. The time refers to the time it takes to field the alternative. A short time is less than one year to field. A medium time is one to three years. Any alternative that takes more than three year has a long time to field. A low cost is defined as costing less than 150,000 dollars a year to operate. A medium cost entails a cost between \$150,000 and \$2M a year. A high cost is anything over \$2M a year to operate. Cost and time are not easy to define since the alternatives are so different.

Cost /Time	Short	Medium	Long
High		Satellite & UAV	
Medium	IWAM	EMP	
Low	Robotic		

A high cost alternative with a long time to field is probably not ideal since money is always an issue and the Army needs a new alternative now to deny the enemy area.

## Conclusions

Based upon our modeling, we were able to make some broad conclusions. From our analysis, conventional artillery takes a large number of rounds to achieve a desired effect. A minimum of 2400 rounds were required to deny an area one kilometer square against an enemy unit with a strength of 14 vehicles. We can see that the number of rounds that would be required to deny an area will be high-cost for the Army. Also, we assumed that the Army would have a supporting indirect firecenter for each denied area, and this proposed use of indirect fire may not always be available. If we could employ this type of alternative effectively, however, the costs to the Army for simply setting aside the indirect fire assets would be tremendous, approximately \$14,000.00 to deny a one-kilometer square area. This type of alternative also has some negative and potentially politically unfavorable aspects. The denied area would in essence become an impact area and would have to be cleared of unexploded munitions. These facts make the strictly indirect fire deterrent alternatives unfavorable. These alternatives include: Satellite, UAV (where the UAV does not have attack capabilities), and Robotics (where the robotic system does not have attack capabilities). A rather obvious conclusion is that if the Army were to opt for an indirect fire type of area denial system then they should use some type of target designator. Smart rounds will increase the effectiveness of the indirect fire and result in fewer rounds required for denial. For target designation to be accomplished though, the Army must use a denial system that has a local observation system that also designates targets (UAV, Robotics, and possibly IWAM).

Another point that became clear to us through our analysis is that a local area denial system offers the greatest likelihood of deterrent. These types of systems (IWAM, Robotic Vehicles, and possibly UAV's) provide a physically present deterrent that discourages the enemy from entering the denied area. One aspect of this idea is the psychological impact of the physical presence of the area denial system to the enemy, an idea that is hard to model. However, the speed of action taken by a physically present denial system is a trait of this type of denial system that can readily translate to increased effectiveness.

The most promising alternative based upon our analysis is the idea of using EMP



to deny an area. This alternative offers rounds that can cover a larger area relative to conventional rounds. This large area covered results in a need for fewer rounds to cover a given area. This makes the EMP alternative potentially cost effective. This alternative also has attributes that make it much more politically acceptable than other alternatives. It can be non-lethal, but it nevertheless remains effective.

### **Recommendation**

Based on the research and modeling that we performed, we recommend an alternative for the short run and another for the long run. For the short run, we recommend that the Army field the IWAM or a Robotics alternative. This alternative consists of existing technology, so it will be cost effective and will not take long to integrate and update to meet the military's current area denial needs. This system can fire its own munitions as well as act as a sensor to aid in employing artillery. It also allows for a physical presence on the battlefield that acts as a deterrent.

However, the future holds more effective and cost efficient means of area denial. For the long run, we recommend that our client develop and field the EMP alternative. This system is the answer to the political problem that accompanies conventional land mines because it is "non-lethal" and has no enduring effects on humans or the environment.

Even though the initial research and development of this system may be costly, it may save the military money in the future because it will take few rounds to effectively deny a given area, as opposed to the current need for large amounts of munitions. This system's long-term benefit will reap great dividends in the current and future needs of area denial.

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# Appendix A: Documentation Sources

## **Section A-1: Robotic Sensor & Attack Vehicle Alternative**

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# **Sandia LabNews**

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February 2, 1995

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## **SARGE robot performs soldiers' duties without the risks**

### **Sandia produces capable, adaptable battlefield prototype**

**By Philip Higgs, Lab News Intern**

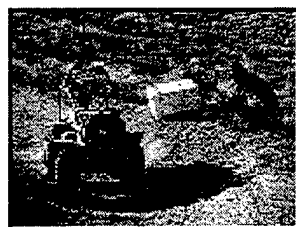
*([back to Lab News contents page](#))*

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For years, both the Army and the Marines have been seeking to develop robots designed for the battlefield, machines that could perform all the dangerous duties of a soldier without all the risk.

"Using robots in war?" you might say. "Yeah, right. A robot could never replace a soldier."

You haven't met SARGE.



*TEARING AROUND THE TRACK - SARGE was shipped to the Army/Marine Joint Programs Office in 1995, but engineer Bryan Pletta (5516) still uses its predecessor, Dixie, to run tests on the Robotic Vehicle Range track southeast of Area 1. Six years of experience with Dixie led designers to create a more adaptable, more capable robot with SARGE. (Photo by Randy Montoya) ([Click on image for page containing larger view](#))*

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SARGE, the Surveillance And Reconnaissance Ground Equipment developed at Sandia's Advanced Vehicle Development Dept. 5516, is the latest standard in a long line of prototype battlefield robots. SARGE is a direct descendent of Sandia's Dixie robot, which was developed in the 1980s.

### **Battlefield tricks**

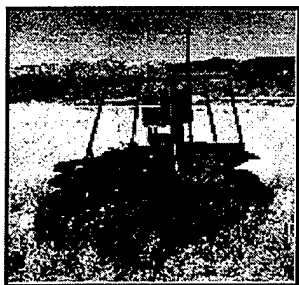
This is no Hollywood robot - a walking, talking, metal humanoid with lasers for eyes, preprogrammed to destroy. Not SARGE. The current mission of battlefield robotics, handed down from the Department of Defense, calls for a much simpler machine, one that would be primarily engaged in remote surveillance.

SARGE and its predecessors have all been four-wheeled, remote-controlled vehicles - not a humanoid part on them. SARGE uses a commercial recreational "four-wheeler," a Yamaha Breeze, as its base platform. A roll cage has been added, and four video cameras, two for surveillance and two for driving, are attached to a pan/tilt platform.

Everything - steering, throttle, cameras - can be operated (or teleoperated) from an operational control unit (OCU) miles away.



Picture this battlefield scene: The enemy lies over a hill, three miles away from your battalion. The sergeant points a finger at you and three others and tells you to check out the situation. M-16s in hand, you head off toward the hill. Halfway there, 10 enemy soldiers spring from nowhere, aiming their rifles at your heads. What happens now?



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*BEFORE ITS completion in April 1995, SARGE was put through over 75 hours of testing. Here it pauses for a quick photo near the Robotic Vehicle Range. (Click on image for page containing larger view)*

---

Or, picture this: You've been selected for the same mission. Instead of grabbing your M-16, you pull out the OCU for your battalion's SARGE unit and send the robot toward the hill, using its cameras to scope out the situation.

Any number of things might happen now, but one thing is for sure: the number of casualties will be less than one.

The SARGE project is not seeking to replace infantry soldiers. The Army and Marines want to use robotics to complement a soldier's abilities, not usurp them. "Obviously, using a robot for surveillance is different from using a person," says SARGE project manager Bryan Pletta (5516). "It's not going to be as good at some things as a person would be, with eyes and ears and a brain. But it doesn't get tired, it doesn't get hungry, it doesn't get sleepy - and it's expendable."

### **A bit of history**

SARGE is a prototype of what will eventually be standard battlefield equipment that will serve as a "force multiplier," something to increase soldier/Marine effectiveness and survivability - known in military jargon as a Teleoperated Unmanned Ground Vehicle (TUGV).

The final, complete TUGV system is expected to be produced in quantity and put into the armed forces inventory. Individual or multiple robots will be assigned to infantry units and battalions.

The TUGV (or "tug-vee," as they say) program was born of a curious union between the Army and the Marine Corps that began in the late 1980s.

Prior to 1988, both services were working separately on two different robot prototypes. DoD realized that the work of the two branches was parallel, and formed the Unmanned Ground Vehicles/Systems Joint Project Office (UGV/S JPO) in 1988 to consolidate their efforts.

Several attempts were made to develop a prototype robot that could be used for reconnaissance missions.

The first was the creation of the Teleoperated Mobile All-purpose Platform (TMAP) that would be adaptable to a number of different missions. Two versions of the TMAP system were developed, but neither was very popular with users.

The next generation in the development cycle was the Surrogate Teleoperated Vehicle (STV).

The STV also failed to live up to the lofty expectations of the military user. Problems with stability and communications prevented the system from gaining acceptance.

So out went the STV, and in came Dixie.

## **Dixie was popular**

According to Bryan, during all of this early testing, "people were coming out and touring our range. A lot of these users had seen Dixie, and they really liked it. They thought it was easy to operate, it didn't turn over easily, it was relatively reliable, and they told the JPO, 'We want something like Dixie. We don't want this STV; we want Dixie.' "

The subsequent request that came out of the Army "specifically asked for a robot like Sandia Labs' Dixie," says Bryan. But by this time Dixie was about six years old, and those involved felt that a number of improvements were necessary.

"We told the JPO that we weren't going to build them Dixie, but something better," Bryan recalls. And thus, the SARGE project was born.

"Dixie far out-performed what was expected of her," says Tom Mayer (5516), a SARGE engineer. "But SARGE gave us the chance to rebuild Dixie from the ground up."

SARGE is equipped with four video cameras in accord with the JPO's current mission of Reconnaissance, Surveillance, and Target Acquisition (RSTA), but also has built-in expansion capabilities to interface with new mission modules as they are developed.

"You could put on a chemical detector, for instance, or a laser designator," says Bryan.

"The key was to provide a system where users could specify what they wanted, and SARGE would be able to handle it."

## **Gaining acceptance**

Another key to the SARGE project is gaining acceptance from its users - the soldiers. "We've taken robots out to demonstrations, and most people like them," says Bryan. But there's one problem. "There's a lot of excitement in some areas of DoD for using robotics with different applications. Most of that is in the project offices or at the higher levels of the military. If you ask an infantry soldier if he likes this idea, more than likely he'll tell you no.

"Right now, using robotics is a pretty radical departure from the way they currently do things," he says.

With SARGE, however, the JPO is taking a new slant in research and development of the final TUGV by getting soldiers' hands on what would essentially be a soldier's tool.

A critical part of the project is the manufacture of eight to ten SARGE units to be given to infantry battalions, getting them involved in SARGE's development up front.

"The program will actually give them to infantry battalions and say, 'This is yours, keep it. Take it home, learn how to use it. Try and figure out what you could do with it if you had one,' " Bryan says.

The JPO is currently under contract with SUMMA Technologies Inc. to build the new units, with Sandia operating as technical adviser.

Obviously, without currently fielded systems, the Army and Marines have no doctrine, no guide, no established practice for using robots. Part of the evaluation process is having the soldiers themselves discover what can be done with such a robot, and developing tactics as they put them to use.

Soldier feedback will also be used to guide subsequent phases of TUGV development.

According to its creators, SARGE is easy to use. With motorcycle-like driving controls and joystick camera controls on a compact OCU the size of a suitcase, the robot is advertised as "user-friendly."

"The neat thing about SARGE is putting someone on it who's never used it before," says Tom. "It takes about two minutes to be comfortable with it. And that's the whole point: getting it as close as we can to the perfect extension."

---

## **SARGE offers quicker response time**

The design criteria for Dixie were low power and low cost, both of which were achieved. Dixie was completed in 1988, when computers were a lot slower than they are now.

Dixie is teleoperated from its Operational Control Unit (OCU) via a 1200-baud radio link, and this, coupled with the slow speed of its processor, causes a 75-millisecond (ms) delay between user command and machine response.

Which is to say Dixie is a little slow when compared to modern counterparts.

"With Dixie, you have to 'drive ahead,' " says Tom. "You have to watch where you're going and plan for what's coming up because of the delay.

"With SARGE, the goal was to match teleoperation to actual use," which meant decreasing that 75-ms lag time.

"We wanted to make it seem like the user was right on top of the machine," he says, "and I think we came pretty close."

Pretty close, indeed. On SARGE, the command/response delay is approximately 20 ms, thanks to its much faster modern processors and communications equipment.

The base platform was also upgraded. Dixie was built on a Honda 125, which relied solely on balloon tires for suspension and required the operator to shift gears while driving. SARGE's platform has a suspension system and a continuously variable transmission (CVT), which doesn't require shifting, making SARGE more stable at high speeds and easier to operate.

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last modified: February 2, 1996

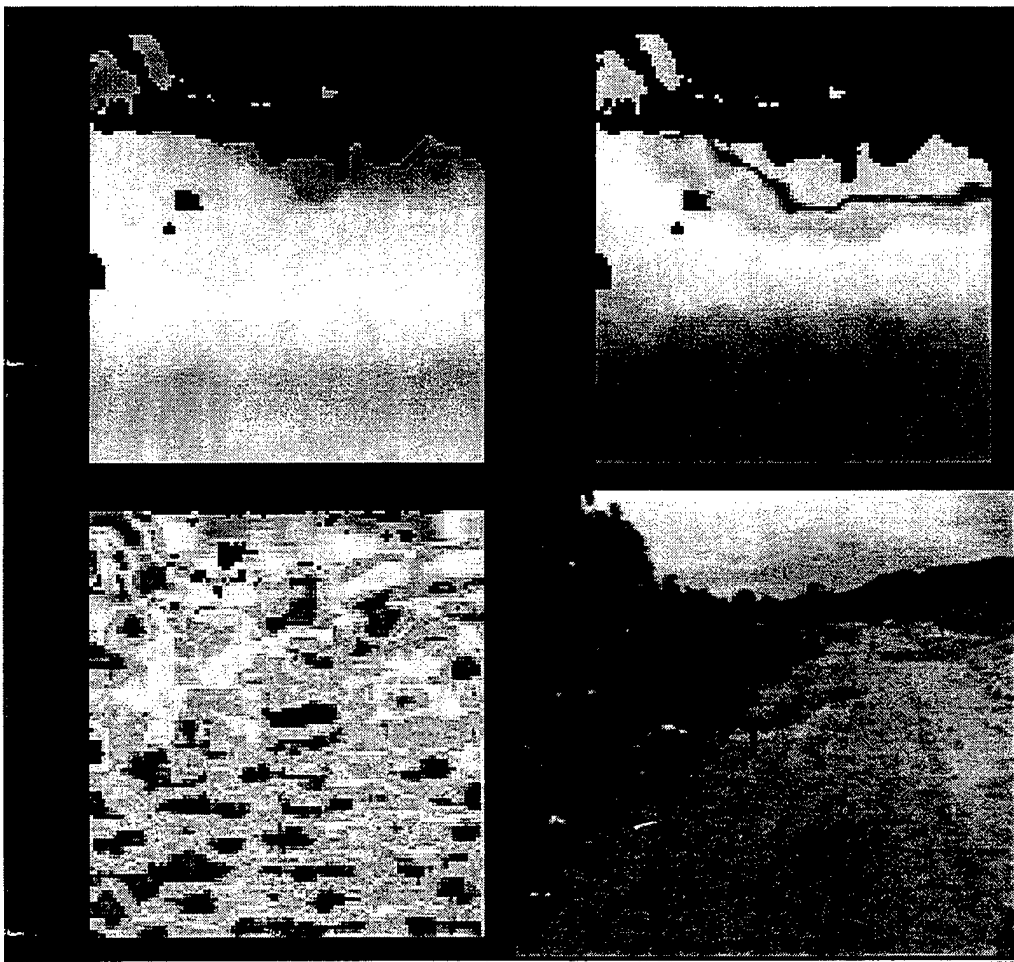
# Wide Field-of-View Stereo

## Introduction

WFOV, the Wide Field-of-View stereo system, is a JPL-based task in DOD's Unmanned Ground Vehicles Project, UGV. It is a real-time system which produces dense range maps from a stereo pair of cameras mounted on a HMMWV ("Hum-Vee"), the military's modern-day Jeep equivalent. The range data is being used by higher-level vehicle-control systems for autonomously navigating around local obstacles encountered during battlefield maneuvers.

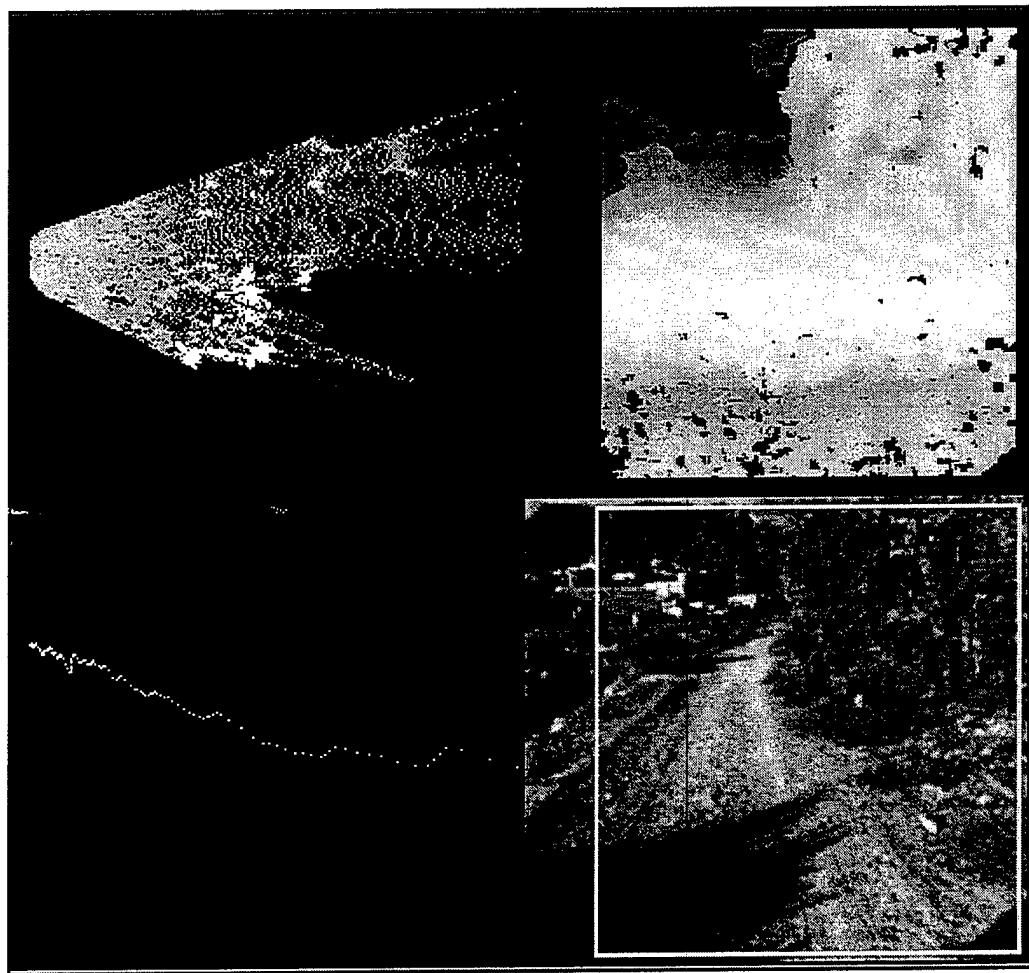
## Example 1

Below is a sample image from an early version of the system. In the lower-right corner is the left image from a stereo pair taken in the Arroyo next to JPL. The upper-right shows range data as distance from the cameras. The upper left contains the subpixel disparity image, produced by the stereo system, from which the range data was computed. The lower-left shows confidence data. In all cases the colors span the rainbow, with red being low values and violet being high values.



## Example 2

Below is a more recent image showing data at a higher resolution. In the lower-right corner is the left image from a stereo pair taken in another part of the Arroyo next to JPL. The blue overlays indicate locations where positive obstacles were found. The red overlays indicate the leading edges of negative obstacles. The upper-right shows stereo disparity (which is related to distance from the cameras). The upper left contains an elevation map of the range data, with the position of the camera off the left edge of the image. The lower-left shows a side plot of a single column of range data (indicated by the vertical blue stripe in the intensity image). In all cases the colors span the rainbow, with red being low values and violet being high values.



## Credits

The stereo algorithms were designed and implemented on an earlier prototype system by Larry Matthies, [Larry.H.Matthies@jpl.nasa.gov](mailto:Larry.H.Matthies@jpl.nasa.gov), of JPL. The WFOV system (and this HTML document) was designed and implemented by Todd Litwin, [Todd.E.Litwin@jpl.nasa.gov](mailto:Todd.E.Litwin@jpl.nasa.gov), also of JPL. Additional software support by Greg Tharp. Larry Matthies is the task manager at JPL for the WFOV task. The system is being integrated into the UGV vehicles at Lockheed-Martin Corporation.

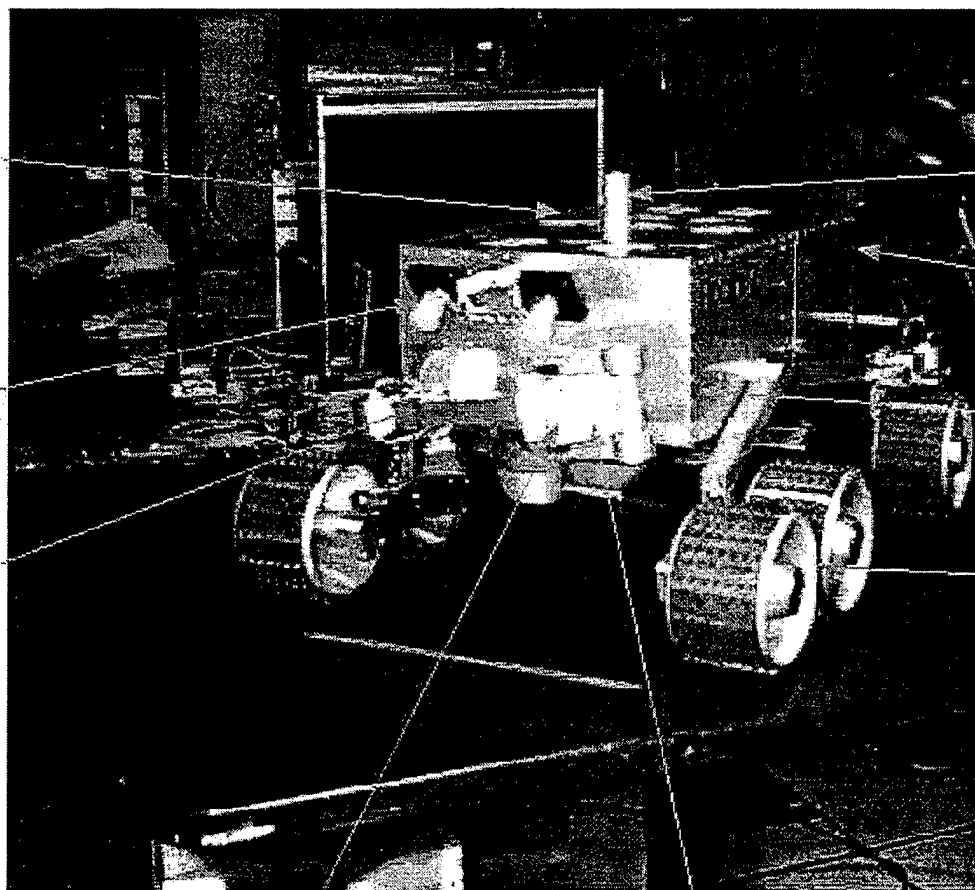
# *Rocky 7*

## Next Generation Research Micro

New Millenium class  
processor and software  
environment

low power stereo vision  
with higher data content

2 DOF stowable arm  
with subsurface reach



2 DOF end-effector for  
digging, grasping and  
instrument pointing

onboard spectrometer  
with fiber optic path  
to end of arm.

# Robotic Vehicles Group



Left to right from top-left: (1) The "blue" rover, a three segment early prototype; (2) Robby, with stereo vision and a puma manipulator; (3) Gofor, with active center of gravity compensation; (4) Rocky 3, with laser light stripe obstacle detection and behavior control; (5) Sojourner, the Pathfinder flight rover, based on Rocky 4 and very similar to Rocky 3 in perception and control; (6) Rocky 7, a next generation prototype with stereo vision and sampling manipulator.

The Robotic Vehicles Group performs research, development, and tests of mobile robots in support of planetary exploration missions and terrestrial applications for NASA and other Government agencies. Current operational vehicles range from microrovers weighing under 5 kilograms that are designed for planetary exploration, to 3,000 kilogram military trucks, to rover testbeds with demonstrated cross-country autonomous navigation capability. Other vehicles include teleoperated robots for investigation of hazardous materials spills. Current activities include the development of an autonomous,

behavior-controlled microrover for science and sample acquisition on the Moon and Mars. The group carries out research in:

- Machine vision
- Terrain geometry estimation
- Local and global vehicle position estimation
- Vehicle control and stability estimation
- Surface properties estimation

An emerging research area involves coordinating mobility and manipulation, then combining them with active force control to accommodate imprecise knowledge either of the terrain or of the motion of the base on which the robotic arm is mounted.

Activities range from basic research in stereo vision to extensive vehicle integration programs that include sensors, actuators, power, and communication systems. Powerful control stations that include stereographic displays for the operator have been developed for effective vehicle commanding. Detailed evaluation and testing of vehicle performance in relevant terrains are major elements of each program.

#### Members:

- Brian Wilcox, Supervisor
- Evelyn Reed, Secretary
- Alberto Behar
- Brian Cooper
- Raymond Cozy
- Todd Litwin
- Thomas McCarthy
- Andy Mishkin, Group Leader
- Jack Morrison
- Tam Nguyen
- Allen Sirota
- Henry Stone
- Edward Tunstel
- Rick Welch
- Takashi Kubota

#### Task Involvement:

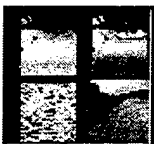


- MFEX: Microrover Flight Experiment



- Long Range Science Rover





- UGV: Unmanned Ground Vehicle



- Hazbot: Emergency Response
- NanoRover

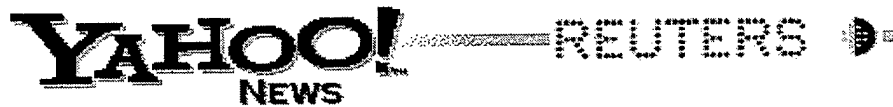
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## **Section A-2: Big Bad Brother in the Sky Alternative-Satellites**

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**Monday October 20 3:32 PM EDT**

## **US Military Fires Laser at Satellite**

By Charles Aldinger

WASHINGTON (Reuters) - The U.S. military has fired a powerful ground-based laser at an Air Force satellite in a test to measure the vulnerability of American satellites to laser attack, the Defense Department said on Monday.

Army Col. Richard Bridges, a Pentagon spokesman, said the results of Friday's test -- in which the Army's "Miracl" laser based at White Sands, New Mexico, was fired successfully at an aging satellite -- were still being determined.

Bridges said two powerful light beams, the first of less than one second duration and the second about 10 seconds, were fired from the "Miracl" laser at the orbiting satellite on Friday night, U.S. Mountain Daylight Time.

"It was illuminated by the laser. The results are still being studied," Bridges told Reuters of the first such firing of a U.S. laser at a satellite.

Defense Secretary William Cohen on Oct. 2 approved a plan to use the Mid-Infra-Red Advanced Chemical Laser (Miracl) at White Sands to illuminate the satellite. The test had been delayed several times by cloudy weather before Friday's shot.

The Pentagon has repeatedly said the "illumination" of the satellite by potentially destructive beams of light would not violate any treaties and was not an attempt to build a satellite killer weapon.

Instead, the department said, it was an attempt to measure whether a laser beam could damage the satellite's ability to operate.

Miracl produces a beam of light six feet across using millions of watts from burning fuel. An extended beam of light from the laser would be capable of burning up a target.

The laser's target was the U.S. Air Force Miniature Sensor Technology Integration program's third satellite, which according to the Pentagon has exceeded its useful lifetime.

The laser was fired at the satellite with only a few days to spare before the orbit of the satellite will be

changed on Thursday to save battery power. That change would move it out of range of the laser.

Even if the shot did not violate any treaties, some State Department officials have privately voiced concerns that the test might cause repercussions in Russia, where members of parliament have balked at ratifying the Start-2 nuclear arms reduction treaty.

The U.S. Army has test fired lasers at missiles and other objects in test flights before, but has never tested them against a satellite.

Military officials have said the controversial satellite test was aimed only at achieving a greater understanding of how to protect U.S. satellites from laser attacks.

But defense experts also say the test might provide data that could be used to refine the laser for future military conflicts or to develop other lasers for anti-satellite use, envisioned in the futuristic U.S. weapons program of the 1980s known as "Star Wars."

The United States has not shown it can destroy satellites, but the development of any U.S. weapon to dominate space arms could in turn, endanger American satellites, according to analysts.

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- [U.S. Test Fires Military Laser at Satellite](#) - Mon Oct 20 2:18 pm

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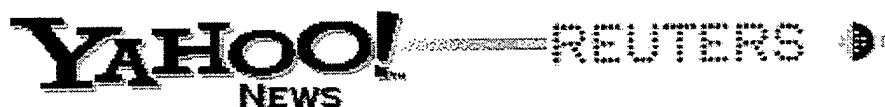
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Monday October 20 2:18 PM EDT

## U.S. Test Fires Military Laser at Satellite

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Army Col. Richard Bridges, a Defense Department spokesman, told Reuters that the results of Friday's test -- in which an Army laser based at White Sands, New Mexico, was fired at an aging satellite -- were still being determined.

Defense Secretary William Cohen approved the test this month and the Pentagon said it would not violate any treaties and was not an offensive attempt to destroy the aging satellite but to test whether brief, intense beams of laser light could damage its ability to operate.

Bridges said two beams, the first of less than one second duration and the second of about 10 seconds, were fired from the "Miracle" military laser at the satellite high above the earth on Friday night, U.S. Mountain Standard Time.

"The results are still being studied," he said.

The laser's target was the U.S. Air Force Miniature Sensor Technology Integration program's third satellite, which according to the Pentagon has exceeded its useful lifetime. Cloudy weather earlier this month had delayed plans to use the Mid-Infra-Red Advanced Chemical Laser (Miracle) to illuminate the satellite.

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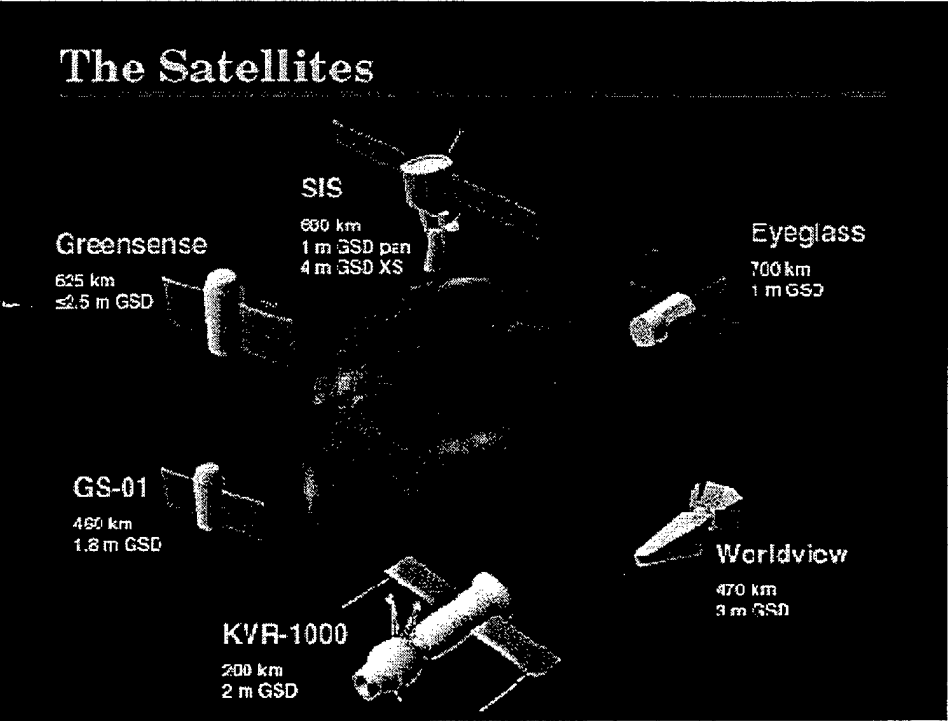
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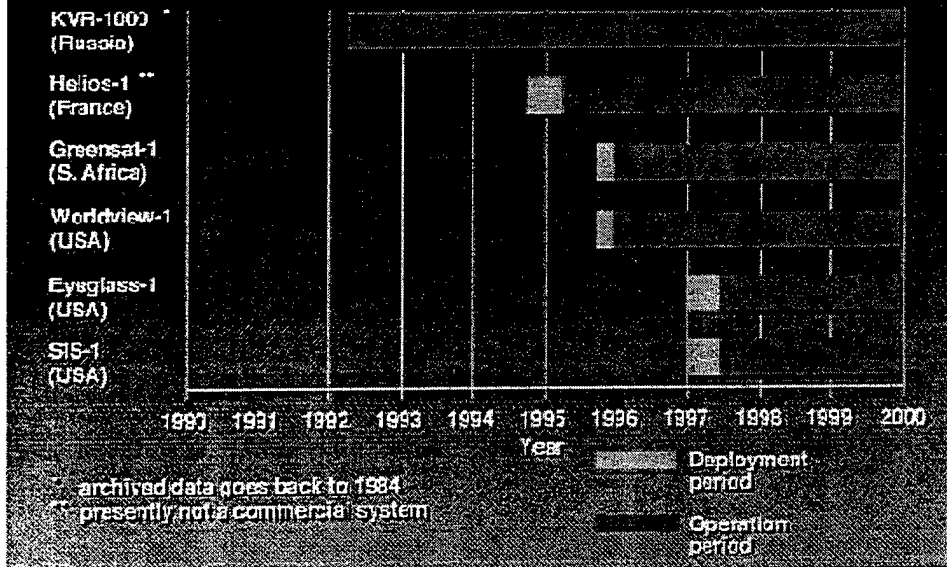
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# The Satellites



As noted earlier, the Russian KVR-1000 is presently the only commercial source for high-resolution satellite imagery. Several commercial satellites carrying high-resolution sensors are scheduled for deployment over the next few years (Figure 1). While all of these satellites will supply similar image products, the technical and operational aspects of each remote sensing system are distinct. The utility of each system can be assessed by considering the technical strengths and weaknesses of the sensors and the associated system architecture. At the present time, there are five image products-one existing and four planned-that merit detailed examination.

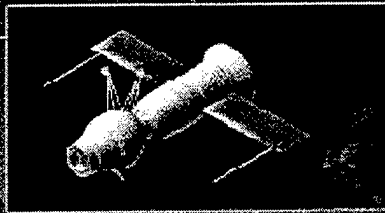
## Timetable for Availability of High Resolution Imagery



## KVR-1000

### KVR-1000

Ground sample distance (GSD)	<2 meters
Spectral range	0.49-0.59 microns
Standard image size	40 x 40 km
Orbital altitude	200 km
Orbital inclination	60°



Artist's Conception

KVR-1000 is an exemplary product of the Russian space program; it was designed with the minimal functions needed to perform its mission. The satellites are deployed into a low orbit of 200 km so that the sensor can get as close a look at the ground as possible. Images are acquired on photographic film which is delivered by ejected canisters. [12] The mission duration is limited to a several-week period due to the finite amount of film and fuel for counteracting atmospheric drag effects. At the end of the operation, the satellite reenters the atmosphere and much of the hardware is recovered and reused.

The KVR-1000 images are panchromatic (0.49-0.59 micrometer) and are sold in both film and digital format. Both commercial formats are spatially degraded to an equivalent GSD of 2 meters. The standard film product covers a 40 x 40 km area. The standard digital products cover areas from 4 x 4 km up to 40 x 40 km. The pixel value range for the digital products is 0-255 (that is, 8 bits per pixel).

Although KVR-1000 images are for sale, key technical parameters of the camera system including the total field of view and film orientation remain unknown. Nor is it clear whether the camera can view areas obliquely-either to the left and right of the satellite ground trace or in front of and behind the satellite. As a result, it is not clear whether the KVR-1000 system can acquire stereo images, and the revisit frequency of the satellite remains unknown. [13]

The operational aspects of the system are a mystery as well. The compilation of the priority acquisition list, the programming of the camera, the production of the final image products, and the retrieval of archived images are not transparent processes. Consequently, KVR-1000 users cannot accurately forecast the amount of time required to fulfill an image order. [14]

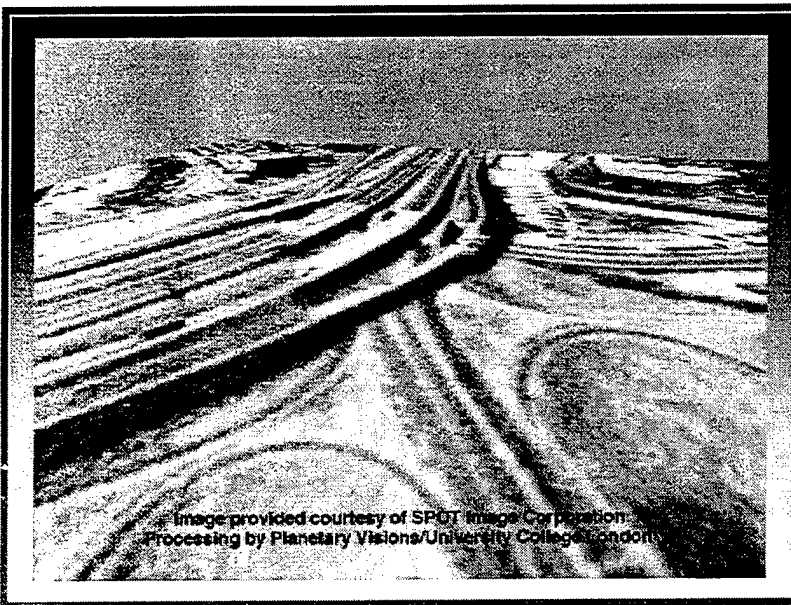
The lack of detailed information on KVR-1000 and the operational problems associated with the remote sensing system can be attributed to the satellite's use by the Russian intelligence community. KVR-1000 is still tied to the culture of secrecy where the release of information on capability (and incapability) is instinctively resisted. And since the camera is still used for intelligence purposes, the insight that could be gained from more technical and operational details cannot be confined exclusively to historical studies and commercial ventures.

Nonetheless, despite the many drawbacks of KVR-1000, the images do contain more spatial detail than any other satellite image on the market today. Plates 1 and 2 are processed KVR-1000 images of the Pentagon and nearby Shirley Highway (Interstate 95). The raw data was acquired from overhead and rendered as perspective views to clearly depict the height and depth of features within the image. At an equivalent GSD of 2 meters, the observer can readily perceive the height of the Pentagon and adjacent structures from the natural shadowing. And on the Shirley Highway shown in Plate 2, it is possible to discriminate between cars and trucks even though the image appears speckly (i.e., moderate signal-to-noise ratio). While it is not possible to identify the make of the vehicles, the spatial detail is good enough to detect traffic jams during rush hour. [15]





**Plate 1. KVR-1000 image of the Pentagon rendered as a perspective view.**



**Plate 2. KVR-1000 perspective view of Shirley Highway (Interstate 95).**

Although requests for image acquisitions cannot be done in near real-time, the spatial detail within the images is good enough to describe and analyze manmade structures as well as detect physical changes over periods of months or years. Yet, at the present time, the systematic use of KVR-1000 for intelligence applications remains confined to Russia. Whether customers outside of Russia will be able to benefit from KVR-1000's intelligence utility will ultimately depend on the decoupling of KVR-1000 from Russian intelligence demands. Even if the commercial component could be run autonomously in the near future, KVR-1000 is only a first-generation remote sensing system. While it may serve as a source of old, high-resolution images for reference purposes, KVR-1000 does not have many of the technical capabilities currently under development by the foreign competition.


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## Greensat

Greensat		
	GS-01	Greensense
Ground Sample Distance	1.8 meters	<2.5 meters
Spectral range	0.5–0.9 microns	0.5–0.9 microns
Scan line width	8 km	10–12 km
Photogrammetric accuracy	<800 meters	<800 meters
Maximum viewing angle	45°	45°
Maximum areal coverage in single orbital pass	132 km <sup>2</sup>	~300 km <sup>2</sup>
Revisit period at equatorial latitudes	2 days	2 days
Orbital altitude	460 km	525 km
Orbital inclination	72°	97.9° (sun-synch)
Digital recorder	No	Maybe

Greensat is a technological outcome of the dramatic political changes within South Africa and the former Soviet Union. Its origin can be traced back to 1985 with the creation of Houwteq—a division of the Denel Aerospace Group. [16] Houwteq was established to design, manufacture, and deploy a reconnaissance satellite for the South African Defense Force. However, the removal of Soviet and Cuban support from Angola in 1988, South Africa's withdrawal from Namibia in 1989, and the collapse of the Soviet Union in 1991 brought the rationale for a South African reconnaissance satellite into question. Government support for the project waned resulting in the conversion of the military program to a commercial venture.

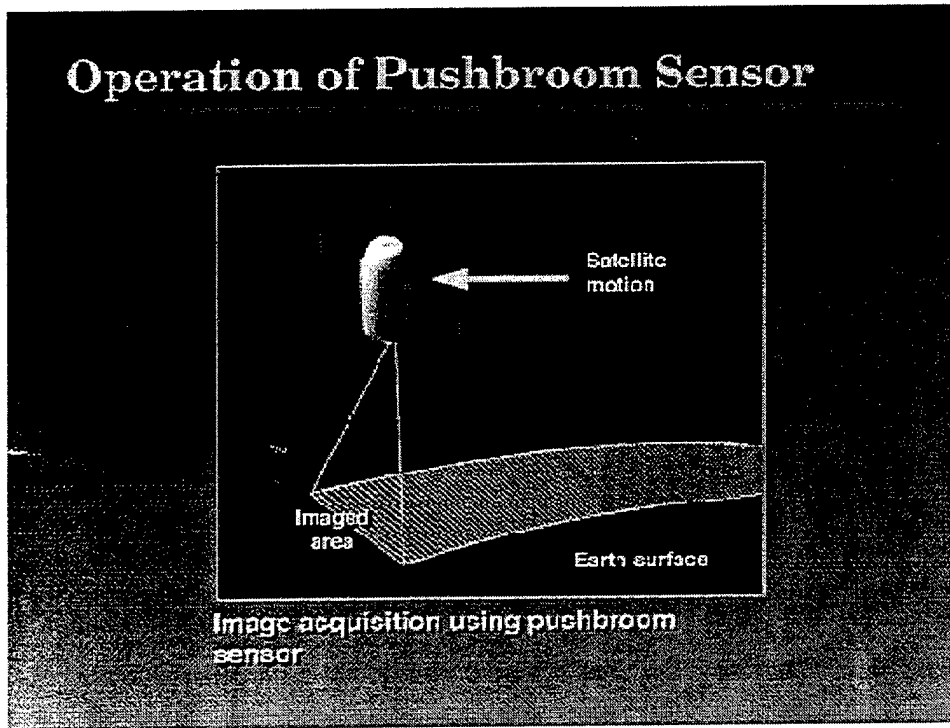
The defense conversion entailed the revision of Houwteq's marketing strategy for Greensat. As the commercial name for the satellite indicates, Houwteq repackaged its remote sensing system as a resource for environmental monitoring and land management. While Greensat has a limited spectral capability for such tasks, its most marketable feature is still the application it was originally designed to do—intelligence gathering.

The first Greensat, GS-01, is scheduled for deployment in late 1995. The satellite will be placed into a circular orbit of 460 km at an orbital inclination of 72 degrees. At this inclination, the local time of day for each satellite overpass will vary at regular intervals. In addition, the satellite will not pass over northern and southern latitudes greater than 72 degrees (e.g., the Arctic Ocean and Antarctica).

GS-01 will consist of a multispectral mapping camera and a high-resolution camera. The multispectral sensor consists of two spectral bands—red and near infrared. The sensor does not have a high-resolution imaging capability (16-meter GSD at a 460-km orbital altitude). The high-resolution camera has been designed to acquire panchromatic images at a 1.8-meter GSD. The camera is sensitive to radiation at

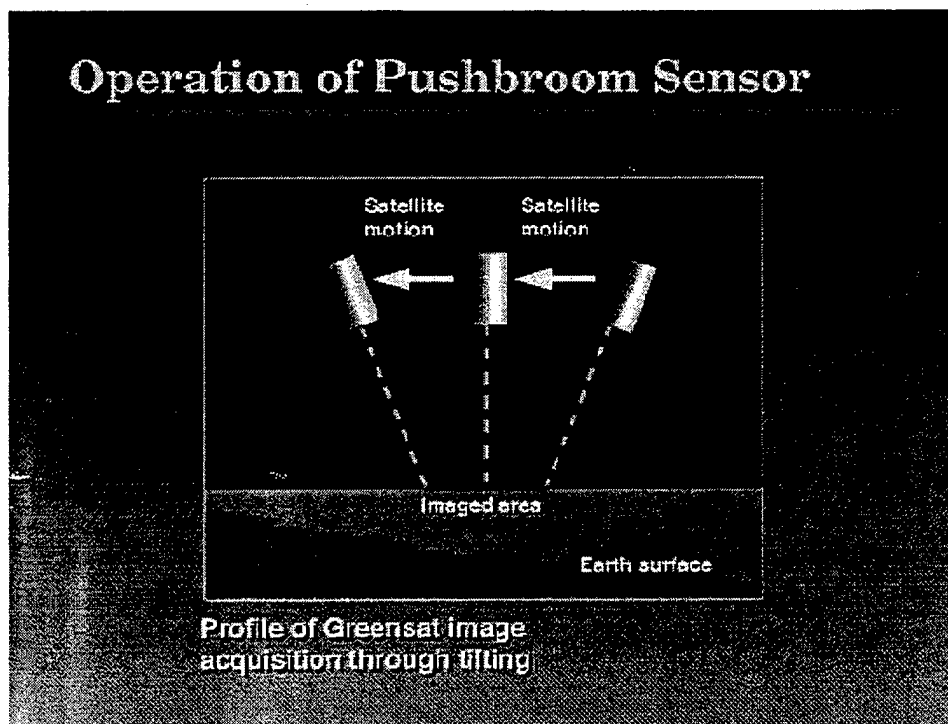
wavelengths between 0.5 and 0.9 micrometer which includes the green, red, and near infrared portions of the electromagnetic spectrum.

The high-resolution camera consists of a linear array of charge coupled devices (CCDs). The two-dimensional image is acquired through the motion of the satellite relative to the ground. As shown in Figure 2, the image is collected in a manner that is analogous to the use of a pushbroom on a floor. The width of the scanned line is 8 km at a 460-km orbital altitude.



**Figure 2. Image acquisition using pushbroom sensor.**

To minimize grainy or speckly effects on the image, Greensat has been designed to increase the signal-to-noise ratio by maximizing the sensor dwell time-the allowable time to collect radiation from a specific ground area. This is done by tilting the satellite so that the sensor can look forward to begin acquiring the area of interest (Figure 3). For Greensat, the entire satellite has to be rotated because the sensor position relative to the satellite is fixed. As the satellite passes over the area of interest, the satellite looks down and then tilts back to complete the image acquisition (Figure 3). Compared with continuous viewing straight down, this procedure results in a significantly longer dwell time. [17]



**Figure 3. Profile of Greensat image acquisition through tilting.**

Besides enhancing the signal-to-noise ratio, the tilting of the satellite permits the acquisition of stereo images. Greensat can obtain a stereo pair in one orbital pass through fore and aft viewing of the area of interest or on separate passes through viewing to the left or right of the orbital track. Areas on the ground can be observed at viewing angles as high as 45 degrees although imaging at angles greater than 13 degrees will degrade the spatial resolution of the acquired scene. The revisit frequency of Greensat is estimated to be every 2 days at equatorial latitudes. The frequency could decrease if the satellite is heavily used and required to perform multiple rotational maneuvers between image acquisitions.

If the dwell time is maximized, GS-01 will acquire an image with a ground coverage of 8 x 5.5 km. Given that this is a relatively small image size, Greensat has been designed to have a pointing accuracy of better than 800 meters in order to minimize the chance of missing or clipping a geographic area of interest. Pixel locations converted to geographic coordinates without the use of ground reference points will have an error no greater than 800 meters.

GS-01 will not have the capability to store images on-board. As the images are acquired digitally, the data will be transmitted in real time to a regional ground station within view of the satellite. The global coverage of GS-01 will ultimately depend on the distribution of regional ground stations; GS-01 will only be able to acquire images of areas within 2000 km of a Greensat-compatible ground station.

Following the deployment of GS-01, Houwteq plans to deploy Greensense—a constellation of Greensats. The constellation is planned to consist of three Greensats deployed in a sun-synchronous orbit at a 625-km altitude. Such an orbit will enable Greensat to acquire images between 82 degrees N and 82 degrees S and view the Earth below at the same local time of day.

The technical capabilities of the satellites within the constellation will slightly differ from GS-01. The high-resolution camera will acquire images at a scan line width of 10 km rather than 8 km. In addition, it may be modified to have a GSD of less than 1.8 meters. [18] On-board data storage may be added to acquire images of areas where no ground station may be present and delay data transmission until a

particular ground station comes into view.

Greensense was conceived to accommodate heavy user demand. Each Greensat will orbit the Earth 16 times per day and be able to acquire 8-10 standard 10 x 10-km images per Earth orbit. That translates to an image acquisition capability of 128-160 images per day for each satellite or 384-480 images per day for the constellation.

Houwteq plans to begin deploying satellites for Greensense in late 1997. One Greensat is scheduled for deployment every six months, so the triplet is planned to be fully operational by the end of 1998. [19] If market conditions are favorable, Houwteq will also develop and deploy up to three modified Greensats carrying a synthetic aperture radar (SAR). A Greensat SAR can acquire images under conditions where the optical Greensats cannot. Because a SAR illuminates the ground with microwaves, it can penetrate cloud cover, and it can acquire images at night.

Although the design is still in the preliminary stages, Houwteq plans to construct a SAR that operates in the X-band (3 cm) with a processed pixel size of 3 meters or better. If an adequate signal-to-noise ratio can be attained, Greensat radar imaging could theoretically resolve small structures that act as good electrical conductors or corner reflectors such as vehicles, aircraft, and buildings.

The distribution of Greensat operations will be similar in concept to the zone defense in basketball. Prospective Greensat customers will negotiate with Houwteq for privileged use of the satellite over certain geographic regions. While the exact terms for use may vary from contract to contract, the substantive issues will include the deployment of Greensat-compatible ground stations, the authority to compile the priority acquisition list within a specified geographic area, and the distribution rights for acquired images of the region. The area of jurisdiction could be confined to economic and political boundaries, or it could expand up to the reception footprint of the ground station (2000-km radius).

From the perspective of operational efficiency, Houwteq will have a strong incentive to define jurisdiction areas that coincide with the ground station footprint and ensure no geographic overlap between ground stations controlled by different customers. This arrangement would avoid many of the potential conflicts in acquisition requests between political adversaries or economic competitors. [20]

While exclusive usage of Greensat over a geographic region could be negotiated, Houwteq will maintain control of all Greensats. Houwteq will perform the necessary housekeeping to keep the satellite functional, and will program the satellite for image acquisitions according to the negotiated arrangements with the customers. If customers do not abide by the terms of their contracts, Houwteq can suspend all pending acquisition requests.

If a customer wishes to have complete control of Greensat or would like to modify the sensor package, Houwteq is prepared to consider the sale of the entire system. Houwteq's selling price is not known, but cost estimates have been provided. The development and construction of Greensat has been estimated to be US \$30-40 million. Estimates of the launch cost for Greensat (total mass 320 kg) vary from US \$3.5 million to US \$13 million. [21] Thus, the sale price for one Greensat with a design lifetime of 2-5 years could be comparable to the average unit cost of one F-117A stealth fighter. [22]

The sale of Greensats would be a marked escalation in the international race to supply high-resolution imagery. Although Houwteq has not committed to such a strategy, the export route could become more attractive if Greensat fails to bring in enough international clients that seek the imagery rather than ownership of the system. The United States is likely to be the most influential factor for Houwteq to consider. Whether Houwteq chooses to export its systems will largely depend on future US policy

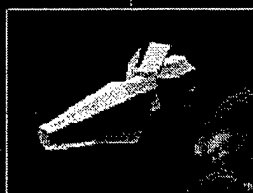
developments on the sale of remote sensing satellites and on the emergence of US companies as suppliers of high-resolution imagery.



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## WorldView

WorldView	
Ground Sample Distance	3 meters
Spectral range	0.45–0.8 microns
Coverage of 2-D array	4 @ 3 x 3 km
Photogrammetric accuracy	40–50 meters
Maximum viewing angle	30°
Maximum areal coverage in single orbital pass	1800 km <sup>2</sup>
Revisit period at equatorial latitudes	4.75 days
Orbital altitude	470 km
Orbital inclination	97.3° (sun-synch)
Digital recorder	Yes (2 Gbytes storage)



The WorldView Imaging Corporation was established in January 1992. Led by personnel with experience in the engineering of US defense systems including Brilliant Pebbles, the company has set out to develop, deploy, and operate its own commercial remote sensing satellites. It is presently building its first two satellites--WorldView-1 and WorldView-2--under a license issued by the US Department of Commerce in January 1993.

Like the first Greensat, WorldView-1 is scheduled for deployment in late 1995. And like Greensense, the satellite will be placed into a sun-synchronous orbit, enabling the sensors to view latitudes between 82 degrees N and 82 degrees S, and image the Earth below at the same local time of day. The orbital altitude for WorldView-1 will be 470 km--155 km lower than the planned orbit for Greensense. At 20-day intervals, the satellite will travel over 305 orbital tracks--each one tracing a distinct path over the Earth's surface. WorldView-2 will be the identical twin of WorldView-1; it is scheduled for deployment in mid-1996. It will be placed into one of the WorldView-1 orbital tracks, and it will also travel over all 305 traces at 20-day intervals. [23]

Each WorldView satellite will carry one multispectral sensor and one high-resolution sensor. The multispectral sensor will acquire images in three spectral bands at a 15-meter GSD. The spectral coverage of the three bands--green, red, and near infrared--corresponds closely with the spectral capability of the multispectral sensors on the French SPOT satellites. The high-resolution sensor will acquire panchromatic images (0.45-0.80 micrometer) at a 3-meter GSD.

Unlike the high-resolution sensor designed for Greensat, the WorldView sensor will be a two-dimensional array of CCDs. Rather than acquire images in pushbroom mode (Figure 2), it has been designed to acquire images of the ground at one instant in time—just as an ordinary camera records an image onto film with one click. Such a sensor is relatively insensitive to spacecraft jitter and simplifies the modeling of the camera geometry for photogrammetric applications.

Images from the high-resolution sensor will consist of four distinct 3 x 3-km areas (36 square kilometers total). Although this is a relatively small field of view, the sensor can image up to 1800 square kilometers by acquiring a series of connecting 36-square-kilometer images as the satellite passes overhead. The sensor is mounted on a two-axis gimbal so the mosaic can be compiled by rotating the sensor along and across the orbital track. In addition, the sensor can be tilted to acquire a series of stereo pairs in one orbital pass. Areas on the ground can be observed at a maximum viewing angle of 30 degrees. With this oblique imaging capability, each WorldView satellite will have a revisit frequency of every 4.75 days at equatorial latitudes.

To assist the photogrammetric application of the data, the WorldView remote sensing system will measure the position and orientation of the satellites as images are acquired. This ancillary data will be provided with the imagery so that end users can measure the location of features within the images without the use of ground reference points. Using the ancillary data, geographic measurements derived from a stereo pair will have an error of 40-50 meters.

In contrast with Greensense, the WorldView system architecture relies on on-board data storage instead of a large network of regional ground stations. For all parts of the world within its view, the WorldView satellite will be able to acquire images and store the data on its 2-Gigabyte solid-state recorder. This recorder will be able to hold 500 uncompressed, high-resolution images where each scene covers 36 square kilometers. The data will be downloaded when the satellite comes within line-of-sight of a WorldView-compatible ground station.

The system architecture will consist of only three regional ground stations—one in Alaska, one in Europe, and one in the central United States. One of these ground stations will be transportable. The Alaskan and European ground stations will be situated at high northern latitudes and thus will be able to communicate with the WorldView satellites on virtually every orbit (i.e., every 95 minutes).

The global application of the WorldView system relies heavily on the functionality of the on-board recorder. If this subsystem fails, WorldView Imaging will add more regional ground stations and collaborate with existing ground stations for real-time data transmission. Although technical, operational, and financial issues associated with such a contingency could temporarily disrupt the WorldView system, the resulting network of ground stations would partially compensate for the loss in global coverage.

The control of the WorldView satellites will be centralized; WorldView Imaging will maintain the satellites and compile the priority acquisition list. Requests for image acquisitions will generally be handled on a first come, first serve basis. However, there are plans to offer a rush acquisition service as well as options for imaging specific geographic locations at regular intervals. Weather conditions at the time of overpass will also be factored into the equation to minimize the wasted imaging of cloud-covered scenes.

Since WorldView Imaging will not parcel out geographic areas to exclusive customers and since the data reception will be centralized, serious acquisition conflicts between different customers could arise if the satellites experience heavy regional or global usage. If the demand for acquisitions exceeds the satellites' operational capacity, the average time lag between image order and image acquisition will inevitably

increase. This could diminish the utility of WorldView for time-urgent tasks unless additional satellites are deployed. [24]

Besides the operation of the satellites, the WorldView system includes a speedy approach for the delivery of the digital data. Customers will be able to obtain recently acquired and archived data in near real-time by accessing the WorldView data via wide area networks (e.g., Internet, Compuserve, etc.). In principal, customers could receive images within hours of acquisition.

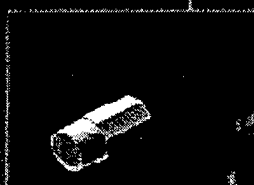
WorldView-1 and WorldView-2 will contain sufficient fuel for 5 years of operation. Follow-on systems could be built that provide images at higher spatial resolutions. Already, WorldView Imaging plans to apply for a license to operate a satellite capable of providing images at 1-meter GSD. Although there are no plans to become a source for satellite hardware, the company foresees growth in the remote sensing market and has focused on establishing itself within that market as a reliable source for high-resolution imagery.



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## Eyeglass

Eyeglass	
Ground Sample Distance	1 meter
Spectral range	0.5–0.9 microns
Scan line width	15 km
Photogrammetric accuracy	<100 meters
Maximum viewing angle	45°
Maximum areal coverage in single orbital pass	14,400 km <sup>2</sup>
Revisit period at equatorial latitudes	2 days
Orbital altitude	700 km
Orbital inclination	98.2° (sun-synch)
Digital recorder	Yes (3.75 Gbytes storage)



The Eyeglass enterprise can be considered a commercial spin-off of remote sensing projects for the US intelligence community. Established in April 1994, Eyeglass International is a consortium of three US firms—Orbital Sciences, Itek, and GDE Systems. The project tasks have been divided among these three companies according to their unique technical strengths. Orbital Sciences will build the satellite bus and launch the system on its Taurus rocket. Itek will develop the sensors and on-board electronics, tapping its experience in the engineering of cameras and electro-optical systems for civilian, intelligence, and military platforms. And GDE Systems will be responsible for the image processing and data handling tasks—an assignment the company has done for the US Defense Mapping Agency as well as for other US government agencies.



Eyeglass is scheduled for launch in mid 1997-about 1-1/2 years after the planned deployment of GS-01 and WorldView-1. Like WorldView-1 and Greensense, Eyeglass will be deployed into a sun-synchronous orbit, so it will have the same geographic coverage under comparable illumination conditions. However, its orbital altitude will be higher--700 km.

In contrast with Greensat and WorldView, Eyeglass will be devoted exclusively to high-resolution imaging. Its single sensor will be able to acquire panchromatic images (0.5-0.9 micrometer) at a 1-meter GSD. The sensor itself will be a linear CCD array of 15,000 elements and will operate in a pushbroom mode (Figure 2). At its planned orbital altitude, the sensor will be able to scan a 15-km width directly below the satellite.

Like WorldView, the sensor is mounted on a 2-axis gimbal; it can scan areas along and across the orbital track up to a viewing angle of 45 degrees. In addition to the acquisition of stereo pairs, the oblique imaging capability can be used to perform more elaborate scanning patterns to view large areas in one satellite overpass. Although the scan line will be limited to a 15-km width, the Eyeglass sensor will be able to scan back and forth like a Zamboni on an ice rink to acquire a 120 x 120-km image of the ground in one overpass. [25] Alternatively, it can acquire a 70 x 70-km stereo pair in one pass by scanning in the first image as the satellite approaches the area of interest and then the second image as the satellite moves away from the area of interest. If Eyeglass performs as designed, it will be able to conduct rapid area surveys over 14,400 square kilometers as well as close-look missions. If a site is too large to be imaged in one overpass, Eyeglass can review the area from a different orbital track in two days or less.

The satellite will carry a GPS receiver to track its position, and it will also carry Earth and sun sensors for satellite orientation. Information about the satellite location and altitude will be supplied with standard image orders to permit ground position accuracies of around 400 meters. More accurate data from the stellar measurements could also be purchased with the imagery, reducing geographic errors to 100 meters or less.

Like Greensense, Eyeglass will use a network of regional ground stations for data reception. The images will either be received as the sensor acquires the data or will be stored on a 3.75-Gigabyte solid-state recorder until a ground station comes into view. The recorder will have a maximum capacity of 60 standard 15 x 15-km images. Eyeglass will orbit the Earth every 99 minutes and will be able to acquire a maximum of 180 standard 15 x 15-km images daily for each ground station. The satellite has been designed for 7 years of operation--5 years at 90% reliability. If the first Eyeglass experiences heavy usage, a second satellite could be deployed in 2000.

Eyeglass operations will be similar to the Greensat architecture. Eyeglass International will maintain the satellite, program the sensors for image acquisitions, and archive digital copies of all Eyeglass images. Foreign distributors will receive the imagery from the satellite, sell the data on an exclusive basis, and have the authority to assemble the priority acquisition list for their region or state.

Eyeglass International is offering two types of privileged cards for its customers-Gold and Platinum. The only difference between the two is the area of jurisdiction. The Platinum agreement covers a geographic region and can be as large as the reception footprint of the ground station (2600-km radius). The Gold agreement is confined to the boundaries of a specific state. For both of these arrangements, the distributor is required to pay Eyeglass International an initial license fee, a guaranteed annual payment over five years, and royalties on all sold images. In addition, the distributor is required to buy and construct a ground receiving and processing station before Eyeglass is launched. Both the Platinum and Gold agreements will be made on a first-come/first-serve basis.

The logic behind the zoning architecture for Eyeglass is a mix of operational and financial considerations. As with Greensat, the division of the globe into exclusive zones would avoid many possible acquisition conflicts between different customers. The choice of zoning according to the ground station footprint or political boundaries increases the attraction of the Platinum agreement while widening the field of prospective customers for the Gold agreement. It also puts pressure on regional adversaries and economic competitors to conclude an agreement with Eyeglass International quickly.

To illustrate this point, consider a hypothetical example involving Country X and its neighboring adversaries. By locking in a Platinum agreement at an early date, Country X would secure usage of Eyeglass to monitor its neighbors while denying its neighbors the ability to use Eyeglass to monitor Country X. [26] If Country X failed to capitalize on its window of opportunity, one of its neighbors could reach a Platinum agreement that covered its territory and subject Country X to systematic monitoring from Eyeglass while denying Country X the option of using Eyeglass in a similar way. Alternatively, Country X could take a "defensive" approach by securing a Gold agreement covering its territory. Country X could then use Eyeglass to image itself and deny its neighbors access to Eyeglass images of Country X. Or each neighboring country could obtain a Gold agreement for its respective territory, denying Country X the ability to monitor its neighbors, thereby undermining the value of a Platinum agreement.

Future operational problems will depend largely on whether the world is divided into a small set of regional jurisdictions (Platinum), a large set of national jurisdictions (Gold), or a mix of both. As noted earlier, a regional network of ground receiving stations with minimal footprint overlap would be ideal from the perspective of operational efficiency. Gaps in the network of ground stations could be filled by allocating these geographic areas to regional distributors and by using the recorder to hold the data until the satellite moved into the station footprint.

A greater number and variety of operational problems are likely to be encountered if Eyeglass is used by distributors with only national jurisdiction. Regions that include several small countries (such as Central America, the Middle East, or Southeast Asia) would be particularly vulnerable to conflicts in acquisition schedules. Since the satellite could pass within view of several small countries simultaneously, Eyeglass International could receive conflicting requests on where the sensor should be pointed and when images should be acquired. In addition, the company and US government could receive diplomatic protests if Eyeglass images fail to accurately exclude areas that lie just across international borders or demarcation lines.

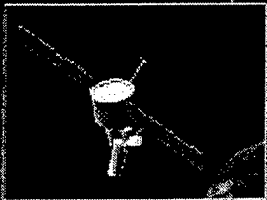
Overall, Eyeglass, on paper, is a technically advanced system with only a few potential drawbacks related to the satellite operation. The smooth interaction between regional and national distributors is a key uncertainty and the prospects for an armada of Eyeglass satellites, if needed, is unknown. Nonetheless, the Eyeglass design has technological advantages over KVR-1000, Greensat, and WorldView. The salient question at this time is whether these design advantages will be realized in the developed system.



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## Space Imaging Satellite (SIS)

SIS	
Ground Sample Distance	1 meter pan, 4 meter XS
Spectral range	Pan: 0.5–0.9 microns XS: 3 bands in visible and near IR
Scan line width	11–15 km
Photogrammetric accuracy	10–14 meters
Maximum viewing angle	30°
Maximum areal coverage in single orbital pass	20,000 km <sup>2</sup>
Orbital altitude	680 km
Orbital inclination	98.1° (sun-synch)
Revisit period at equatorial latitudes	2 days
Digital recorder	Yes



The Lockheed Missile and Space Company conceived SIS in 1991 and formed Space Imaging Incorporated in June 1994 to develop and operate the system. With a 30-year engineering history that goes back to the early days of US reconnaissance from space, Lockheed sees SIS as a means of using its technical expertise to secure a share of the commercial remote sensing market. SIS has been designed as an advanced remote sensing system with many technical features that will directly challenge Eyeglass.

SIS-1 is scheduled for fielding in early 1997, nearly coinciding with the deployment of Eyeglass-1. It has been designed to operate over a mean lifetime of 5 years. A second SIS will be constructed as a spare in case SIS-1 breaks down prematurely, or if market conditions demand the deployment of a second satellite. Like Eyeglass, SIS-1 will also be placed into a sun-synchronous orbit at an approximate altitude of 680 km. The satellite will carry a panchromatic sensor and a multispectral sensor consisting of at least four spectral bands. Both sensors will be capable of acquiring high-resolution images. The panchromatic sensor will acquire images at a 1-meter GSD, and the multispectral sensor will acquire images in the visible and near infrared at a 4-meter GSD. Both will operate in a pushbroom mode at a scan line width of 11–15 km (Figure 2). In addition, both sensors will be able to image areas obliquely in any direction up to a viewing angle of 30 degrees. The satellite's revisit frequency will be every 2 days at equatorial latitudes. The acquired data will either be downlinked to a ground station as the sensor scans the ground or stored on-board until a ground station comes into view.

Outside the United States, the operation of SIS will be delegated to regional franchises who will control data reception, distribution, and archiving. In contrast with the system architecture for the four competing satellites, these franchises will have sole regional authority not only to select areas for imaging, but also to upload the acquisition schedule directly to the satellite. [27] As a result, the area of jurisdiction for each franchise is likely to cover the entire communication footprint of the ground station. As with Eyeglass, gaps between franchises could be filled by relying on the on-board recorder.

The SIS system architecture offers greater autonomy to its regional franchises. By eliminating the need for a middleman to program the satellite, the franchise will have more control over the efficiency of the image acquisition process and greater authority to handle operational conflicts between customers within the region. The relinquishment of central control does have its drawbacks, particularly if it adversely affects

service to customers. [28] A poor performance record could raise concerns about compliance with the conditions of operation in the US Land Remote Sensing Policy Act of 1992. If an imaged country failed to receive images of itself from the regional franchise under reasonable terms and conditions, Space Imaging would be limited to the drastic option of "locking out" transmissions to and from the relevant franchise. Even if such an option were exercised, the imaged country may not receive data of its territory since the franchise would retain possession of the images at issue.

With the support of Lockheed Missile and Space Company in partnership with other firms such as E-Systems, Space Imaging has the technical ability to build a satellite system that approaches the capabilities of US intelligence satellites. While Eyeglass can also be considered a cousin of US space reconnaissance, the SIS concept is slightly more versatile as the images will contain high spatial detail along with color content. In addition, the operational architecture will be more accommodating to the security interests of the franchise's host state. The main challenge for Space Imaging in the near term will be to deliver SIS as a working system at a cost that is competitive with other fielded systems.



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[12] There may also be a capability to scan the film product on-board the satellite and download the image to a ground station electronically. However, if such a capability exists, it is not available on a commercial basis. [Return to text](#)

[13] Stereo imagery consists of two or more images of the same scene acquired at different viewing angles. A stereo pair can be used to view scenes in 3-D and measure the height of imaged features. The revisit frequency of a satellite defines how often a specific geographic point can be imaged. It is a function of the altitude of the satellite, the sensor's ability to view areas to the left and right of the satellite's orbital track, the sensor field of view, the radiometric sensitivity of the sensor, and the geographic latitude of the point of interest.

For an intelligence satellite, this is a sensitive parameter to reveal. If known, observed parties can accurately calculate when they could be imaged and can schedule countermeasures accordingly. [Return to text](#)

[14] At the present time, orders for archived images can take several weeks or months to fulfill and image acquisitions can take place six months to one year after the request was made. [Return to text](#)

[15] If traffic jams can be found in this imagery, it is reasonable to deduce that mechanized force concentrations could also be found. [Return to text](#)

[16] Denel is a South African company that used to work exclusively on government projects. Since 1992, it has gradually moved into commercial ventures outside the government. [Return to text](#)

[17] The increase in dwell time can be illustrated through a simplified example. Consider a flat feature with a length of 18 kilometers. Assume Greensat has a GSD of 1.8 meters. For a circular orbit at a 460 km altitude, the satellite speed is approximately 7.6 kilometers per second relative to the ground. If the camera on Greensat is pointed straight down and aligned with the feature's length, it would image the entire feature in 2.4 seconds (18 km/7.6 km per second). The image would consist of 10,000 rows (18,000 meters/1.8 meter GSD) so the total imaging time would translate to a dwell time of  $2.4 \times 10^{-4}$  seconds per row (2.4 seconds/10,000 rows).

If the satellite is tilted fore and then aft by an angle of, say, 10 degrees during image acquisition (see Figure 3), the camera would image the flat feature over 180 kilometers of its orbital track ( $460 \tan[10 \text{ degrees}] \text{ km fore} + 18 \text{ km} + 460 \tan[10 \text{ degrees}] \text{ km aft}$ ). In this case, the camera would image the entire length of the feature in 23.7 seconds ( $180 \text{ km} / 7.6 \text{ km per second}$ ). Once again, the image would consist of 10,000 rows so the dwell time would be  $2.37 \times 10^{-3}$  seconds per row ( $23.7 \text{ seconds} / 10,000 \text{ rows}$ ). That is an increase by a factor of about ten over the previous case. [Return to text](#)

[18] Houwteq is considering the use of the GS-01 high-resolution camera system for Greensense. If the same camera system is used, Greensense will acquire images at a 2.5 meter GSD over a 12 km scan line width. [Return to text](#)

[19] Greensense may incorporate GS-01 provided it is still operational. [Return to text](#)

[20] This zoning arrangement could still result in acquisition conflicts between two adjacent zones that share the same orbital tracks. Such conflicts are analogous to water usage disputes between upstream and downstream consumers. Consider Zone N located just north of Zone S. As the satellite travels from north to south, it will enter Zone N and be used according to the demands of User N before entering Zone S. Once the satellite enters Zone S, User S could encounter a multitude of operational problems attributable to the way the satellite was used in the northern zone (eg incorrect sensor orientation, lack of on-board storage space, low reserve power, etc.). [Return to text](#)

[21] Ben Iannotta, "Russia Accused of Underbidding to Win Greensat Launch," Space News, Vol. 5, No. 9 (February 28 - March 6 1994), p. 8. All estimates in 1994 dollars. [Return to text](#)

[22] The average unit cost of the F-117A stealth fighter is \$42.6 million (1990 dollars). Mark Lambert, ed., Jane's All the World's Aircraft 1993-94, (London: Butler and Tanner Ltd., 1993), p. 507 [Return to text](#)

[23] To optimize the global revisit frequency of the pair, WorldView-2 will probably be injected into an orbital track where it will always be 153 tracks away (10 days out of phase) from WorldView-1. [Return to text](#)

[24] WorldView Imaging has made contingency plans to deploy additional satellites every 18 months. [Return to text](#)

[25] Although Greensat has been designed to operate a pushbroom sensor and have an oblique imaging capability, it will not be able to scan such a large area in a single overpass. Eyeglass's ability to acquire a  $120 \times 120 \text{ km}$  image in one pass can be attributed to the design of more sensitive CCDs capable of attaining an adequate signal-to-noise ratio from a smaller ground area ( $1 \times 1 \text{ meter}$ ) within a shorter dwell time.

Moreover, the higher orbit provides more time to scan the surface below because the area of interest remains in view over a longer orbital arc and the satellite's velocity relative to the ground is less. For relatively small viewing angles (less than 15 degrees), the length of the orbital arc increases linearly with the satellite altitude. And in accordance with Kepler's third law for a circular orbit, the satellite's velocity is inversely proportional to  $(r_e + h)^{1/2}$  where  $r_e$  is the Earth's radius and  $h$  is the satellite altitude.

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[26] For commercial remote sensing systems operated by US companies, a country must have access to

acquired images of itself even if it does not have the right to use the commercial imaging satellite. This is a condition of operation under the Land Remote Sensing Policy Act of 1992 (Section 202b, clause 2). This condition is also consistent with Principle XII of the 1987 UN General Assembly Resolution of Principles Relating to Remote Sensing of the Earth from Space.

With respect to the hypothetical example, neighbors of Country X would be entitled to Eyeglass images of their own territory that were requested and received by Country X. If Country X failed to make this data available under reasonable terms and conditions, Eyeglass International would provide the images from its central archives within two days. [Return to text](#)

[27] Lockheed will perform all necessary housekeeping tasks and will be able to supersede all commands from the franchises. [Return to text](#)

[28] This problem has been encountered at foreign SPOT and Landsat ground receiving stations. [Return to text](#)



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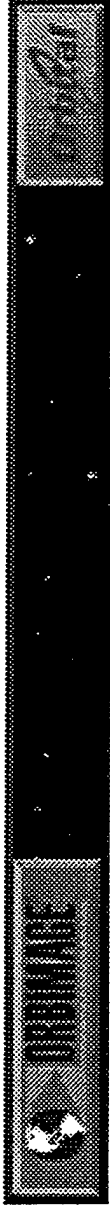
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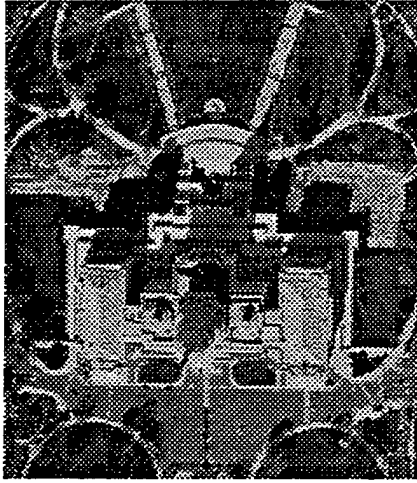


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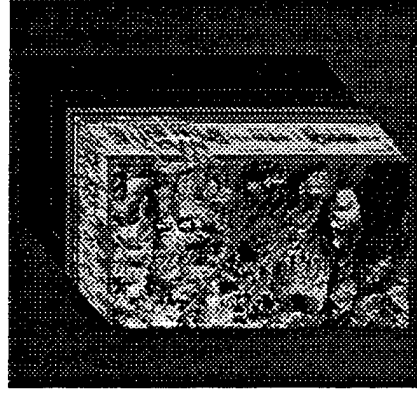
## OrbView-3 Products and Applications



**1 Meter Panchromatic**



**4 Meter Multispectral**



**9 Meter Hyperspectral**

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### Applications of OrbView-3 Data Include:

#### **Agriculture & Forestry:**

- Crop Forecasting and Yield Management**
- Forestry Health Assessment**
- Erosion Management**
- Infestation Assessment**
- Habitat Monitoring**

#### **Environmental Monitoring:**

- Compliance Monitoring**
- Habitat Mapping**

## **Section A-3: Chemical**



# Definition of Chemical Weapons

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The Chemical Weapons Convention, Article 2, paragraph 1 defines "chemical weapons" thus:

"1. "Chemical Weapons" means the following, together or separately:

- (a) Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes;
- (b) Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;
- (c) Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in subparagraph (b)."

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*Last modified 29 April 1997 by [ICA Division, OPCW](#)*

## Research project at Nonmetallic, inorganic materials science

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### Identification of Oxygen Reduction Mechanisms of Solid Oxide Fuel Cell Cathodes

The oxygen reduction mechanism of solid oxide fuel cell (SOFC) cathodes is investigated in detail. Frequency response analysis (Impedance spectroscopy) is used to determine the electrochemical response of perovskites and noble metal cathodes as a function of temperature, oxygen partial pressure and applied electrical potential. The determined electrochemical parameters are used for state space modeling and a detailed step by step reaction scheme is derived. Micro- and nanostructural investigations (atomic force microscopy, SEM, high resolution TEM) are carried out to correlate the cathode performance with microstructural parameters.

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- [Dr. Martin Gödickemeier \(email\)](#)
- Working group SOFC ([email](#))

#### Supported By:

Swiss Federal Office of Energy (BEW)

#### In Collaboration With:

Sulzer Innotec, Winterthur, Switzerland

#### Last Update:

10/06/96

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Updated apr-96 (JH)/ [Jens Helbig \(E-mail\)](#)

## Internal Combustion Engine

Derek Foo 1997

<http://members.tripod.com/~dtpf/index.html>

### A Different perception

The strategy for improving engine efficiency is very straightforward, with just two aspects; firstly, to reduce the power required to propel a vehicle, and secondly to produce the power required for propulsion more efficiently. Whether the motive power comes from any type of internal combustion engine, the fundamental requirement is for efficient operation. Automotive engine efficiency is of personal interest to all engineers employed in the automotive industry. Many attempts in the past proved not much improvement in this aspect.

Fundamentally, an engine is purely a means to convert energy from one form to another. By the simple process of combustion. The process is indicated by one important fact, the combustion of fuel. It is the fossil fuel, in this instance the petrol, which contains the latent chemical energy that is converted into kinetic energy for propulsion. Each litre of fuel contains a specific maximum amount of energy, which can be released during the process of combustion. The output of the engine in the form of power and torque depends solely on the amount of fuel that is burnt. Two factors affect this process. First, as much fuel as possible must be supplied to the point of combustion namely the combustion chamber. **Secondly, sufficiency oxygen for the fuel to burn in must be supplied to ensure complete combustion.** In the case of today's internal combustion engines however, the process is much more complex due to the environmental demands imposed by today's society. Not only do we seek the maximum power and torque from an engine, it should be noted that the engine must be able to respond to loads almost instantaneously, in all kind of operating conditions. Furthermore, the amount of excess fuel should be kept as minimum as possible at the same time in order to maintain a minimal toxic emissions in the exhaust.

Therefore, if an engine is to operate efficiently within these criteria, the combustion process, which includes the metering and delivery of air and fuel to the combustion chambers, must be controlled very accurately. The maximum amount of kinetic energy that can be produced in the combustion process is directly proportional to the actual mass of fuel that is burnt. This is achieved chemically and requires the presence of a specific amount of air. If the efficiency of such a device were 100%, then the power output would be directly proportional to the amount of fuel burnt. In such an instance the supply of more power from the engine would simply involve providing more fuel for conversion.

However, the real world is not so perfect and the efficiencies obtained in automotive engines are relatively poor. This is mainly due to the actual design of the internal combustion engine. If we consider the use of the energy produced in one combustion event, (power stroke) of a four strokes, four cylinders internal combustion engine, it would be easy to see where the wastage occurs. **In one of the other cylinders, some**

of the energy is used to suck air (intake stroke) into the cylinder ready for the next combustion. Another cylinder, energy is being used to compress the air/fuel mixture (compression stroke) for combustion. Whilst in the fourth cylinder, some energy is being used to pump the gases resulting from the previous combustion (exhaust stroke) out of the cylinder. Added to this, energy is wasted in heat and in overcoming friction in the rotating of parts.

Hence, automotive engineers have to contend with many problems to achieve increases in power output. Invariably their efforts are concentrated in improving the power of the engine. It is very easy to increase the delivery of the fuel to the engine. Conversely, **it is very difficult to provide sufficient air to sustain the most efficient combustion.** The early development of pressure charging occurred in the aeronautical industry, where their benefits were quickly realized as a means to overcome losses in engine power at high altitude, caused by the reduction in atmospheric pressure and therefore, the density of the air drawn into the engine. Experience from such developments was soon applied to the automotive industry. During the 1920 - 1930 era pressure charging was the norm for racing engines.

## **Section A-4: Electromagnetic Pulse (EMP)**

Electrical and Electronics Engineers, Inc. (IEEE), and represents the considered judgment of a group of U.S. IEEE members with expertise in the subject field. The IEEE United States Activities Board promotes the career and technology policy interests of the 250,000 electrical, electronics, and computer engineers who are U.S. members of the IEEE.

## BACKGROUND

### I. THE NATURE OF EMP SIMULATOR FIELDS

Both outdoor and indoor electromagnetic pulse (EMP) simulators have been in operation at a number of sites. These simulators generate very brief, single pulses of intense, electromagnetic (EM) fields. This energy replicates the non X-ray portion of the energy (i.e., the non-ionizing radiation) that would be produced if a nuclear weapon were detonated in the upper atmosphere. The non-ionizing EM energy that is produced by an EMP simulator is similar in content to the burst of EM energy produced by lightning discharges in the atmosphere, but significantly briefer. The EM fields generated by EMP can disrupt or damage sensitive circuitry in such electronic systems as computers, communications systems, weapons-guidance systems, and telephone lines. To study the vulnerability of electronic systems and components to the destructive effects of a true EMP pulse, non-nuclear EMP simulators have been developed to test protective measures for electronic systems that might be susceptible to EMP-induced damage.

Significant public misunderstanding exists about the nature of the emissions from EMP simulators. In several crucial respects the fields produced by a non-nuclear EMP simulator are very different from the energy produced by the detonation of a nuclear weapon. Non-nuclear EMP simulators produce no ionizing radiation. Such radiation is produced in large quantities by nuclear detonations and is very hazardous. Also, the spatial distribution of non-ionizing radiation from EMP simulators is quite different from the radiation produced by nuclear explosions. Significant EM fields from EMP simulators are limited to short distances from the simulator (a few miles), but nuclear EMP from weapons exploded at high altitudes might exist for many hundreds of miles.

EMP simulators generate single bursts of non-ionizing EM energy. The instantaneous (temporal peak) intensity of this burst is typically less than 100 kiloVolts per meter, which lasts for approximately one microsecond. The intensity of the EM fields decreases rapidly as the distance from the simulator increases. Measured field strengths outside the boundaries of a typical simulator site are lower than the maximum permissible values for human exposure to RF and microwave energy (as specified by U.S. and international safety standards).

### II. PUBLIC CONCERNS ABOUT THE POSSIBLE ADVERSE EFFECTS OF EMP FIELDS ON HUMANS BEINGS AND THE ENVIRONMENT

Over the past 20 years, several groups have expressed concerns about the possible adverse effects of EMP fields on humans beings and the environment. These concerned groups have included EMP workers, citizens of communities near operational or proposed EMP simulator installations, public interest groups, and legislators in

the Federal and state governments. Environmental impact and personal injury lawsuits have been filed against operators of several outdoor simulators. One large U.S. Army simulator installation in Woodbridge, Va., has permanently halted all outdoor EMP simulator operations as a result of several years of litigation that was initiated by a private environmental law group. During the latter stages of this litigation, operation of EMP simulators was severely restricted or prohibited. In another instance state governments in Maryland and Virginia prohibited a new EMP simulator (EMPRESS II, 1988) from being operated in the Chesapeake Bay, after many years of costly environmental impact studies and public hearings on the subject.

### III. THE LIMITED BODY OF KNOWLEDGE ON THE BIOLOGICAL EFFECTS OF EMP SIMULATOR FIELDS

#### A. Animal and Human Health-Effects Studies

A number of studies have been conducted to address the concerns about the health and safety of EMP simulator workers. Experiments on laboratory animals and epidemiologic analyses of the health records of workers at EMP simulator sites have been performed. In a series of experiments (Skidmore, 1973; Mattsson, 1976; Baum, 1978; Cleary, 1980), several species of laboratory animals, including dogs, rabbits, rats, and monkeys were exposed to a very large number of EMP-simulator pulses (70,000 to 5,000,000) over periods ranging from a few hours to many days. The field strengths to which the animals were exposed ranged from 100 to 450 kV/m using parallel-plate line exposure devices. Within statistical limits, these studies revealed no clinically significant adverse effects in the various physiological and behavioral endpoints that were monitored. However, none of these studies included measurements that could indicate the magnitude of the electric fields or current densities induced in the tissues and organs of the subjects.

In-vitro (test tube) experiments, in which EMP-simulator waveforms were applied directly to solutions of blood cells, did reveal statistically significant changes in erythrocyte cell membrane permeability (Cleary, 1980). These experiments involved field strengths in the in-vitro solutions that were approximately 200 KV/m. Compared to the E-field induced in humans who are exposed to EMP simulator fields, the in-vitro E-fields were about 10 times more intense, and durations were approximately 25 times longer. Limited information is available on the health records of EMP-exposed workers. Bruner (1977) reviewed medical records of more than 600 workers who received chronic exposures to EMP simulator fields. This study, which evaluated data from annual physical examinations, detected no abnormal incidence of disease. Recently, several investigators have conducted a number of experimental studies to assess the effects of EMP fields on coastal and marine wildlife (EMPRESS II, 1988). These studies found no indications of effects on the general health or behavior of these species of fish, birds, and other marine wildlife that were examined. These studies were limited to less than ten species of animals. Each study involved only a small number of subjects (typically one to ten) and considered only a few biological and behavioral endpoints. However, a detailed review of EMP-related bioeffects literature was published by Aldrich, et al., in 1988. Many abstracts and an extensive bibliography are presented. This paper concluded that adverse biological effects are not evident in the literature. The study concludes that more data on internal fields and current densities are needed in order to compare existing (non-EMP) radiofrequency bioeffects data to the conditions that occur during

EMP exposures.

B. Studies of the Fields and Currents Induced in Humans and Animals Exposed to EMP Simulator Fields

Several engineering studies have evaluated the amount of energy absorbed by human beings exposed to fields from EMP simulators. Measurements (Gronhaug, 1988) and computations (Lin, 1975; Gronhaug, 1986; Guy, 1989; Chen, 1991) determined the magnitudes of electrical currents induced in the body. These studies indicate that the induced current is in the form of a very brief but intense impulse. The waveform of the current is a highly-damped sinusoid wave with a fundamental frequency component of approximately 30-50 MHz. This impulse has a peak amplitude of approximately 500 Amps (current density = 140,000 A/m<sup>2</sup>). When an adult standing on the ground is exposed to an EMP pulse with a 5 nsec risetime and a peak external, vertically-polarized E-field of 100 kV/m, the maximum induced electric field strength occurs in the ankles and has a peak value of about 150 kV/m. These studies indicate that in spite of the very high peak internal E-field and current densities, the energy absorbed by any part of the body is extremely small (less than 0.2 J/kg). Each pulse can induce a temperature rise of no more than about 50 microdegrees Celsius at any region within the body.

Data on the induced fields and currents in animals exposed to EMP-simulator fields are very limited. One recent study measured the total current induced in the body of laboratory rats in a parallel plate transmission line (Mathur, et al., 1990). The exposure conditions were similar to those used in prior studies of EMP bioeffects on rats. The animal body was perpendicular to the electric field vector. The total current flowing through the animals' bodies to the ground plate on which they were standing was approximately 1.5 Amps peak when using an exposure field of 70 kV/m. Values of maximum spatially-localized current densities and the corresponding specific absorption values were not determined.

Recent computations have estimated the localized current densities and specific absorption induced in computer models of adults, children, and infants, as well as small monkeys, standing upright on the ground while exposed to a 100 kV/m vertically polarized EMP simulator field (Guy, 1990). These values are virtually independent of the height of the subject, as long as the ratio of the height of the body to the diameter of the body, legs, and ankles remains constant.

C. Limitations of Past Studies of the Effects Of EMP Simulator Fields On Animals

The data cited above on induced currents, current densities, and internal E-fields in humans and in animals exposed to the same external "EMP simulator" waveform and field strength raise significant questions of the relevance of the findings of many of the prior studies of bioeffects on animals. These findings cannot be used directly to predict human health effects of EMP simulators. The discrepancy between induced currents in animals versus humans beings becomes smaller for studies involving larger animals, such as dogs (Baum, 1978). Other inadequacies in past studies include the limited types of biological effects studied, particularly for long-term exposures. Thus, any new studies of EMP fields that are performed on laboratory animals should use better exposure techniques and well-quantified induced current densities. If the current densities and induced E-fields are comparable to those



induced in human beings exposed to EMP fields, an improved basis for extrapolating the findings to hypothetical EMP exposures of human beings will result.

D. Relationship Between EMP Exposure and Exposure To Other Kinds of Intense, Pulsed Non-Ionizing Radiation

The most thorough studies of the biological effects of intense, pulsed EM fields have been performed using high, peak-power pulsed microwaves, or "high power microwaves" (HPM). The fields from HPM sources are similar to EMP simulator fields in many ways. Therefore, the findings of studies of HPM bioeffects can provide valuable information to those interested in the bioeffects of EMP. HPM bioeffects studies have featured precise measurements of the induced peak electric fields and the rate of energy absorption in localized regions of animal subjects. Information is available on the mechanisms of interaction of HPM transient exposures, and the threshold-induced field and energy levels that induced effects. Several researchers have exposed laboratory animals to pulsed microwave fields whose pulse widths and peak external electric field strengths were similar to those of EMP simulator fields (Creighton, 1987; D'Andrea 1988; Klauenberg, 1988; Wachtel, 1989; Lin, 1989). These studies involved exposures of up to several hundred pulses per day. In general, the results indicate that only one parameter appears to produce acute effects: the instantaneous local temperature rise. "Biologically ineffective" exposures were those that induced less than 0.1 degree Celsius local temperature rise. Thus, high instantaneous peak electric field strengths and high rates of energy absorption have not been shown to cause biological effects, if the exposures induce low levels of energy in localized regions or the entire body.

The results cited above can be loosely extrapolated to the case of intense, very brief pulses from sources such as outdoor EMP simulators. The threshold for biological effects was related directly to the local energy density induced in animals exposed to single pulses or to bursts of multiple pulses. The instantaneous peak intensity of the electric field was not found to be a significant factor in producing effects with exposures that induced transient temperature elevations below 0.1 degrees Celsius in any region of the subject's body. The threshold of effects for brief bursts of pulsed microwaves is approximately one thousand times higher than the energy density induced in any region of the human body when human beings are exposed to typical EMP simulator fields.

IV. RELEVANT SAFETY STANDARDS

Many safety standards have been promulgated by various national and international organizations to regulate exposures of personnel to EM fields in the radiofrequency range (ANSI, 1982; ACGIH, 1990; IRPA, 1988). All of these standards deal directly with continuous wave (CW) and conventional amplitude-modulated non-ionizing radiofrequency electromagnetic fields and with the time-averaged value of amplitude modulated and pulsed RF. Most of the safety standards address only hazards of intense, transient electromagnetic fields by imposing limits on the time-averaged energy delivered or absorbed by the human body. The intensity and brevity of EMP fields, as well as their instantaneous rate of energy absorption differ significantly from the sources of RF fields that are addressed by these safety standards.

Therefore, new safety standards that address the temporal peak of

intense, brief pulsed EM fields are needed. These standards must address the high induced electric field strengths and current densities in various parts of the human body. Several of the latest revisions of existing RF safety standards address this issue directly (ACGIH, 1984), (DODI, 1986), (IEEE SCC28, 1991).

The safety standards cited above, which address transient RF fields, limit human exposures to pulses with a peak electric field strength of 100 kV/m. These limitations generally are based on the premise of limiting the total energy absorbed by a human being over a period of several minutes. Also, recent standards address the issue of protecting personnel from the possibility of electrical shock and RF burns when touching large metal objects during exposure to very intense RF transient fields. EMP simulator pulses fall well within these limits. Based on present knowledge, the above standards appear to offer protection from any known hazard of intense pulsed EM fields, including those generated by EMP simulators. Additional considerations for effects of long-term exposures are needed in future revisions of these standards. This requires an improved biological effects data base and accompanying dosimetry to address these issues adequately.

#### V. CONCLUSIONS AND RECOMMENDATIONS

There is significant public concern about the potential hazards to persons exposed to the fields produced by EMP simulators, as well as the impact of these fields on the environment. At the present time, there is no notable evidence of potential harm to persons exposed to these fields. This is due to the lack of bioeffects found in experimental studies of animals exposed to intense but very brief (sub-microsecond) EMP and microwave fields. In addition, no known biophysical mechanisms of interaction exist for these types of induced fields and current impulses. Therefore, given current knowledge, IEEE-USA believes that there is no threat to persons or the environment from repeated exposures to fields from EMP simulators. There are several existing and newly proposed safety standards for exposure of human beings to intense pulsed radiofrequency EM fields. Conforming with these exposure guidelines should provide a significant margin of safety for persons working or living near EMP simulator sites.

Despite the data cited above, there are gaps in our knowledge of the effects of chronic exposures to EMP fields. Several methodological flaws exist in virtually all studies of the biological effects of EMP exposures of laboratory animals. This creates a situation which leaves unanswered certain public concerns about EMP simulators. Therefore, we believe that additional research on the biological effects of EMP exposures should be performed using laboratory animals. These studies should feature exposure methods that induce peak, transient electric fields in the animals' bodies that are equal to those induced in human beings who are exposed to EMP simulator emissions. These new studies should be performed by interdisciplinary teams of biomedical scientists and engineers familiar with the principles of electromagnetic field coupling to biological subjects and with the latest information on the mechanisms of interactions of EM fields with biological systems.

#### REFERENCES

ACGIH (American Conference of Governmental and Industrial Hygienists). "Threshold Limit Values for Radiofrequency/Microwave

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# ALCMS GIVEN NONLETHAL ROLE

DAVID A. FULGHUM/WASHINGTON

## U. S. retrofitting older cruise missiles to carry disabling warheads that could be used to settle regional conflicts with a minimum of civilian casualties

**T**he Defense Department is retrofitting hundreds of its older, long-range air launched cruise missiles to improve their stealth characteristics and adapt them to carry conventional and new families of nonlethal but disabling warheads that could be useful in conflicts like that in the Balkans.

The Air Force AGM-86 air-launched cruise missile in particular is being modified as they are pulled out of the nuclear attack role. Most notably, some of the 1,500-mi.-range missiles will be fitted with a nonnuclear, electro-magnetic pulse (EMP) generator.

An EMP missile, flying at low altitude into an area with key enemy command and control sites, can explode, thus producing a momentary burst of microwaves powerful enough to disable all but special, radiation-hardened electronic devices.

The headquarters of a large army unit or a naval task force exposed to attack by a number of EMP weapons would be left "blind, deaf and dumb," a Washington-based defense analyst said. "They are not that expensive" and they would create "widespread havoc with electronics in short order."

Air Force officials confirmed that ALCMs are being shifted to new conventional attack and decoy roles, but refused comment on EMP-warhead development. The capability would be invaluable, "but I'd keep it in my hip pocket [secret] until I needed to use it," a senior official said.

A nonnuclear EMP burst is produced by creating a magnetic field in a coil and then squeezing it by the detonation of conventional explosives. The resulting pulse of microwave energy can carry thousands of feet and damage or upset electronic components. In early 1993, private automobiles parked about 300 meters from a U. S. EMP generator test site had their coils, alternators, electric seats and electronic engine controls accidentally disabled by the pulse.

During the Cold War, researchers in

## CLINTON ORDERS NEW DESIGN FOR SPACE STATION

WASHINGTON

**T**he Clinton Administration has ordered NASA to redesign the space station once again to reduce costs. The savings would be put into other space programs and aeronautics research.

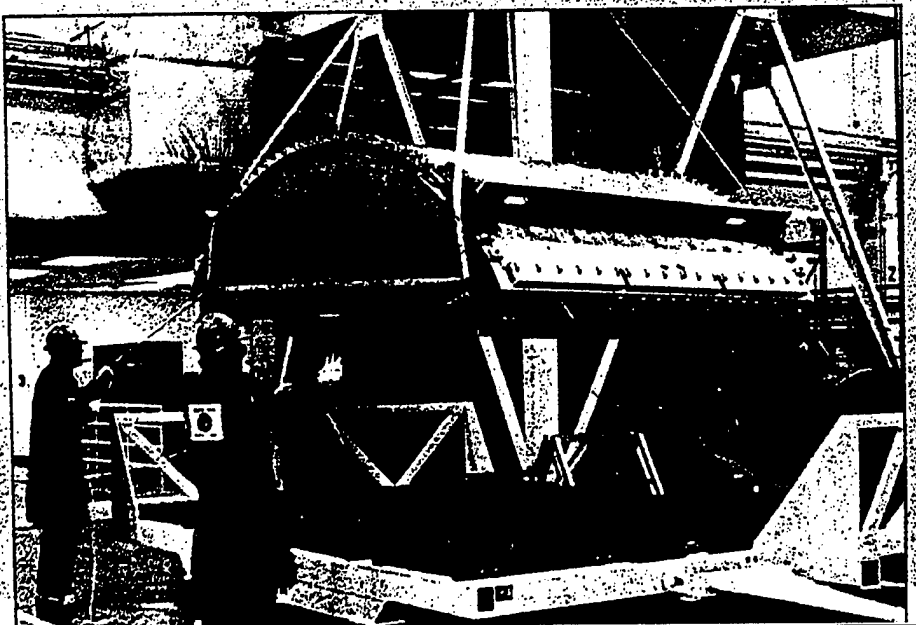
The president will propose a \$14.7-billion budget for NASA for Fiscal 1994, up from \$14.1 billion this year. The space station would receive \$2.305 billion. If approved by Congress, that will boost station spending from this year's \$2.1 billion, but still fall short of the \$2.5 billion the space agency had planned.

NASA Administrator Daniel S. Goldin told AVIATION WEEK & SPACE TECHNOLOGY he is delighted that the new administration wants to rein in station costs and boost aeronautics spending:

"I was frustrated that the program was out of balance," he said. "It would be unconscionable if we proceeded with a fully funded space station—given the tremendous budget deficit problem this country has—at the expense of not start-

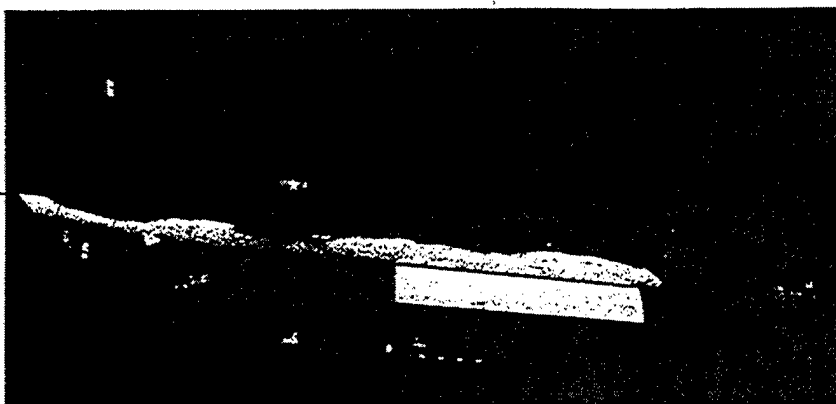
ing any new activities in [lightweight, lower-cost] spacecraft. It would be a crime for NASA not to step up to a vigorous aeronautics program."

"We don't know what it's going to look like," Goldin said of the new station design that will emerge. But he said, at least for the time being, no station contracts will be canceled.



Boeing's first item of qualification hardware, an aluminum section of a space station node, is moved after baking in an autoclave in Huntsville, Ala.

Hundreds of the Defense Dept.'s older air launched cruise missiles are being made more stealthy and reequipped with non-lethal warheads.



the former Soviet Union developed an EMP weapon, a magneto-cumulative generator at the Arzamas 16 nuclear weapons laboratory near Nizhny Novgorod.

In the wake of the Persian Gulf war, U. S. defense officials confirmed to AVIATION WEEK & SPACE TECHNOLOGY that the U. S. was researching its own EMP weapons at Los Alamos National Laboratory, N. M., and Eglin AFB, Fla., as part of a nonlethal, disabling weapons program.

The U. S. Army's Training and Doctrine Command developed a still unreleased operational study for such weapons last

year. It specifically mentioned the use of high-powered generators to "degrade enemy [intelligence] collection, processing and communications systems." Such an attack would "allow the Army to hide, friendly forces' intentions and disposition," the report said.

On a localized basis, EMP generators also could damage solid-state ignitions on vehicles, detonators, communications, radar and aircraft electronics. On a wider stage, the disabling of key

computers could stop a belligerent state's production and distribution of electricity, natural gas, petroleum, oil and lubricants without destroying production facilities.

However, the physical dimensions of the EMP generator, and possibly other nonlethal weapons, has forced the Defense Dept. to redesign some ALCMs into shapes that have been described as "non-traditional, strange, non-aerodynamic," by an observer. A "bulbous, pointed ogive [nose cone]" shape is broken by a flat, down and forward-angled surface near its nose.

The flat panel is optically transparent

The president settled on the new plan for NASA after two weeks of infighting at the White House—a high-level debate from which even Goldin was often excluded. At various points, it seemed Clinton might move to cancel the station altogether, fully fund it or cut the program back substantially.

CLINTON'S BROAD AIM seemed clear: to bring total station costs down without inflicting even more layoffs in the beleaguered aerospace industry. But many of the details remained uncertain: late last week, as top station officials both in the U. S. and abroad complained that the White House had left them in the dark or carelessly tossed about terms and figures.

On Capitol Hill, White House officials said the station would be budgeted at about \$1.8 billion a year in 1995-98, according to sources familiar with the closed briefings, which took place before the president released the details of his economic plan. However, Goldin said he had not been given "out-year" budget targets for the station but was merely told to reduce the station's life-cycle costs.

Goldin said Clinton had directed him "to redesign the space station as part of a program that is more efficient and effective and capable of producing good returns on our investment... a streamlined, cost-effective design, assuring stability during the transition and minimizing any potential job losses."

The order also appears to assure that Goldin will remain at NASA's helm for some months, though he said he knew nothing of a reported 60-90-day deadline for the redesign.

Goldin told NASA and contractor employees Feb. 18, the redesign "is not a problem. This is a challenge."

But with some \$8 billion spent on developing the orbital base over nearly a decade that has included half a dozen redesigns or program overhauls, many involved in the program are skeptical. Station contractors, led by Boeing, McDonnell Douglas, Rocketdyne and Grumman, have begun drawing detailed blue-

prints and making test articles and even some flight hardware. So slips are seen as inevitable in the current schedule to launch the first elements in mid-1996 and complete the station in mid-2000.

NASA's international partners are concerned about the impact on them. Ian Pryke, the head of the European Space Agency's office here, said ESA would "make it very clear that we expect to be involved" not only in the redesign but in setting the ground rules for the redesign. Representatives of Japan and Canada expressed similar concerns.

According to the president's report, A Vision of Change for America, Clinton's budget for NASA will increase to \$15.5 billion in 1995 and keep growing slightly each year through 1998, when it will reach \$16.6 billion.

IT ALSO SAID Clinton would ask to spend some \$2.636 billion over the years 1994-98 on NASA to "redesign space station and invest in new technology."

In a table of "investment proposals," including a section on "technology and business reinvestment and defense conversion," the report said the Administration would add new spending of \$817 million over the same period on NASA civil aviation and an additional \$70 million on NASA short-haul aircraft research.

Part of what led the new administration to order NASA to restructure the station program was the prospect that the agency would not be able to keep the effort on schedule and under budget. The biggest threat of a cost overrun looms in so-called Work Package 2, in which NASA's Johnson Space Center oversees prime contractor McDonnell Douglas (AW&ST Feb. 8, p. 20).

Criticism of the work package reached a new plane, even for the controversial station program, when a U. S. senator, Sen. Bob Krueger, (D-Tex.), called for—and got—the removal of NASA's station manager in Houston, John Aaron.

# EMP WEAPONS LEAD RACE FOR NON-LETHAL TECHNOLOGY

DAVID A. FULGHUM/WASHINGTON

The electromagnetic pulse generator is emerging as one of the strongest contenders from among dozens of technologies in the U. S. military's race to find effective weapons to defeat an enemy without causing loss of life.

It is known that "as you vary the electromagnetic field, you can produce upset of electronic devices by scrambling digital memories or causing the device to destroy itself by diverting current to sensitive components," according to a senior scientist at Los Alamos National Laboratory.

THEREFORE, the services are pressing ahead in research on small devices that can generate "ultra wide-band, high-power microwaves" that can be used to "disable any vehicle [trucks, missiles and aircraft] dependent on electronic circuits to operate," according to an unreleased document produced by the Army's Training and Doctrine Command. This research thrust has been confirmed by defense, research and industry officials.

Initial tests of the U. S.'s first nonnuclear, electromagnetic pulse (EMP) weapon earlier this year were flawed but promising, according to Pentagon and industry officials.

The device, which uses conventional explosives to generate a highly directional EMP strong enough to disable or damage electrical equipment, "didn't quite do everything we expected [it] to," a senior Pentagon official said.

But an aerospace industry insider said the results were effective enough to unintentionally damage the ignitions and engine controls of privately owned automobiles about 300 meters from the test site. The cars were not part of the experiment, but the effects upon them were exactly what experimenters are looking for.

The EMP generator is being developed by the Air Force and sized to fit into air-launched cruise missiles (ALCMs) that have been modified with bulbous new noses. The altered noses are constructed of many small, flat panels, somewhat like a miniature version of the F-117's skin. A trapezoidal, optically transparent panel in the nose is used both as an opening for target sensors and as an exit route for the narrow EMP beam.

Secrecy-shrouded testing of an EMP-generator weapon has been conducted within the last four years at Los Alamos National Laboratory and is currently ongoing at Eglin AFB, defense and industry officials confirmed.

While Los Alamos officials will not discuss military applications of EMP generators, a similar technology is being employed there for peaceful research in plasma physics, high-pressure chemistry and fusion power.

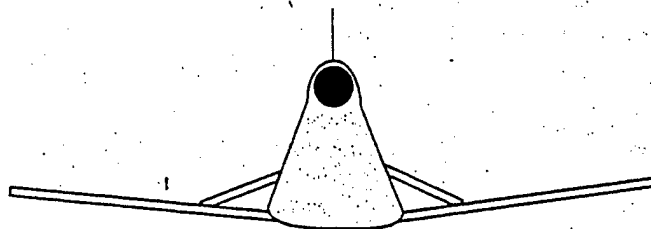
Scientists have developed a high explosive-driven pulsed power generator consisting of a helical coil wrapped around a copper cylinder filled with high explosives. A bank of capacitors supplies an initial current of a few hundred thousand amps that creates a magnetic field in the gap between the coil and cylinder. The explosion compresses the magnetic field and creates a very short-duration pulse of high power, according to the senior Los Alamos scientist.

The militarized Air Force EMP generator is said to differ from the Los Alamos device in that the explosives surround the electronic coil, an aerospace industry official said. In the Air Force's effort, compression of the explosion then helps produce a highly directional EMP pulse.

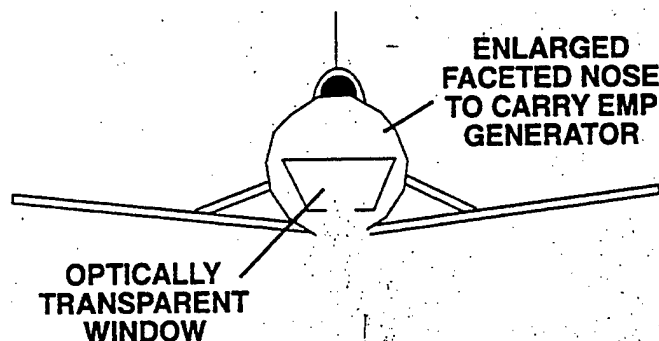
DURING A RECENT TEST, Los Alamos' 2-ft.-wide by 10-ft.-long Procyon-design generator produced a 12-16-million-amp pulse with a rise time of only 400 nanoseconds, a Los Alamos official told AVIATION WEEK & SPACE TECHNOLOGY. The effective power of over four trillion watts "exceeded the electrical generating capacity of the rest of the planet," he said.

The Russians, who pioneered nonnuclear EMP weapons work during the Cold War, have reported extensive work with explosive-driven generators for peaceful purposes with capabilities substantially ahead of U. S. designs, a pulse power specialist said. Experiments using

## STANDARD AIR-LAUNCHED CRUISE MISSILE



## ALCM MODIFIED TO CARRY NON-LETHAL ELECTROMAGNETIC PULSE (EMP) WEAPON



30°  
EMP  
BEAM

large disk-shape designs have produced pulses of over 200 million amps. Smaller 16-in.-wide by 40-in.-long versions of the Russian-designed generators produced about 30 million amps, he said. The U. S. Air Force has had to work with similar small-sized generators to fit into modified Air Launched Cruise Missiles, and the 30-million-amp output is not greatly different from the power generated by the Air Force's EMP weapon, an aerospace industry official said.

But "it's not so much the power as the ability to focus the output" that concerns the military, he said. "The key is depositing energy at the right range on a target."

The Air Force's EMP weapon uses a "well-tuned, average-tech antenna" that operates much like the reflector dish behind a flashlight bulb, the aerospace official said.

The antenna focuses the generator's output within "about a 30-deg." swath to concentrate on a specific target within several hundred meters of the missile. ■

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## Electromagnetic effects of nuclear explosion

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The high temperatures and energetic radiation produced by nuclear explosions also produce large amounts of ionized (electrically charged) matter which is present immediately after the explosion. Under the right conditions, intense currents and electromagnetic fields can be produced, generically called EMP (Electromagnetic Pulse), that are felt at long distances. Living organisms are impervious to these effects, but electrical and electronic equipment can be temporarily or permanently disabled by them. Ionized gasses can also block short wavelength radio and radar signals (fireball blackout) for extended periods.

The occurrence of EMP is strongly dependent on the altitude of burst. It can be significant for surface or low altitude bursts (below 4,000 m); it is very significant for high altitude bursts (above 30,000 m); but it is not significant for altitudes between these extremes. This is because EMP is generated by the asymmetric absorption of instantaneous gamma rays produced by the explosion. At intermediate altitudes the air absorbs these rays fairly uniformly and does not generate long range electromagnetic disturbances.

The formation EMP begins with the very intense, but very short burst of gamma rays caused by the nuclear reactions in the bomb. About 0.3% of the bomb's energy is in this pulse, but it last for only 10 nanoseconds or so. These gamma rays collide with electrons in air molecules, and eject the electrons at high energies through a process called Compton scattering. These energetic electrons in turn knock other electrons loose, and create a cascade effect that produces some 30,000 electrons for every original gamma ray.

In low altitude explosions the electrons, being very light, move much more quickly than the ionized atoms they are removed from and diffuse away from the region where they are formed. This creates a very strong electric field which peaks in intensity to 10 nanoseconds. The gamma rays emitted downward however are absorbed by the ground which prevents charge separation from occurring. This creates a very strong vertical electric current which generates intense electromagnetic emissions over a wide frequency range (up to 100 MHz) that emanate mostly horizontally. At the same time, the earth acts as a conductor allowing the electrons to flow back toward the burst point where the positive ions are concentrated. This produces a strong magnetic field along the ground. Although only about  $3 \times 10^{-10}$  of the total explosion energy is radiated as EMP in a ground burst ( $10^6$  joules for 1 Mt bomb), it is concentrated in a very short pulse. The charge separation persists for only a few tens of microseconds, making the emission power some 100 gigawatts. The field strengths for ground bursts are high only in the immediate vicinity of the explosion. For smaller bombs they aren't very important because they are strong only where the destruction is intense anyway. With increasing yields, they reach farther from the zone of intense destruction. With a 1 Mt bomb, they remain significant out to the 2 psi overpressure zone (5 miles).

High altitude explosions produce EMPs that dramatically more destructive. About  $3 \times 10^{-5}$  of the bomb's total energy goes into EMP in this case,  $10^{11}$  joules for a 1 Mt bomb. EMP is formed in high altitude explosions when the downwardly directed gamma rays encounter denser layers of air below. A pancake shaped ionization region is formed below the bomb. The zone can extend all the way to the horizon, to 2500 km for an explosion at an altitude of 500 km. The ionization zone is up to 80 km thick at the center. The Earth's magnetic field causes the electrons in this layer to spiral as they travel, creating a powerful downward directed electromagnetic pulse lasting a few microseconds. A strong

vertical electrical field (20-50 KV/m) is also generated between the Earth's surface and the ionized layer, this field lasts for several minutes until the electrons are recaptured by the air. Although the peak EMP field strengths from high altitude bursts are only 1-10% as intense as the peak ground burst fields, they are nearly constant over the entire Earth's surface under the ionized region.

The effects of these field on electronics is difficult to predict, but can be profound. Enormous induced electric currents are generated in wires, antennas, and metal objects (like missiles, airplanes, and building frames). Commercial electrical grids are immense EMP antennas and would be subjected to voltage surges far exceeding those created by lightning, and over vastly greater areas. Modern VLSI chips are extremely sensitive to voltage surges, and would be burned out by even small leakage currents. Military equipment is generally designed to be resistant to EMP, but realistic tests are very difficult to perform and EMP protection rests on attention to detail. Minor changes in design, incorrect maintenance procedures, poorly fitting parts, loose debris, moisture, and ordinary dirt can all cause elaborate EMP protections to be totally circumvented. It can be expected that a single high yield, high altitude explosion over an industrialized area would cause massive disruption for an indeterminable period, and would cause huge economic damages (all those damaged chips add up).

A separate effect is the ability of the ionized fireball to block radio and radar signals. Like EMP, this effect becomes important with high altitude bursts. Fireball blackout can cause radar to be blocked for tens of seconds to minutes over an area tens of kilometers across. High frequency radio can be disrupted over hundreds to thousands of kilometers for minutes to hours depending on exact conditions.

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## The E-Bomb - a Weapon of Electrical Mass Destruction

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### ABSTRACT

High Power Electromagnetic Pulse generation techniques and High Power Microwave technology have matured to the point where practical E-bombs (Electromagnetic bombs) are becoming technically feasible, with new applications in both Strategic and Tactical Information Warfare. The development of conventional E-bomb devices allows their use in non-nuclear confrontations. This paper discusses aspects of the technology base, weapon delivery techniques and proposes a doctrinal foundation for the use of such devices in warhead and bomb applications.

### 1. Introduction

The prosecution of a successful Information Warfare (IW) campaign against an industrialised or post industrial opponent will require a suitable set of tools. As demonstrated in the Desert Storm air campaign, air power has proven to be a most effective means of inhibiting the functions of an opponent's vital information processing infrastructure. This is because air power allows concurrent or parallel engagement of a large number of targets over geographically significant areas [SZAFRANSKI95].

While Desert Storm demonstrated that the application of air power was the most practical means of crushing an opponent's information processing and transmission nodes, the need to physically destroy these with guided munitions absorbed a substantial proportion of available air



assets in the early phase of the air campaign. Indeed, the aircraft capable of delivery laser guided bombs were largely occupied with this very target set during the first nights of the air battle.

The efficient execution of an IW campaign against a modern industrial or post-industrial opponent will require the use of specialised tools designed to destroy information systems. Electromagnetic bombs built for this purpose can provide, where delivered by suitable means, a very effective tool for this purpose.

## 2.The EMP Effect

The ElectroMagnetic Pulse (EMP) effect [1] was first observed during the early testing of high altitude airburst nuclear weapons [GLASSTONE64]. The effect is characterised by the production of a very short (hundreds of nanoseconds) but intense electromagnetic pulse, which propagates away from its source with ever diminishing intensity, governed by the theory of electromagnetism. The ElectroMagnetic Pulse is in effect an electromagnetic shock wave.

This pulse of energy produces a powerful electromagnetic field, particularly within the vicinity of the weapon burst. The field can be sufficiently strong to produce short lived transient voltages of thousands of Volts (ie kiloVolts) on exposed electrical conductors, such as wires, or conductive tracks on printed circuit boards, where exposed.

It is this aspect of the EMP effect which is of military significance, as it can result in irreversible damage to a wide range of electrical and electronic equipment, particularly computers and radio or radar receivers. Subject to the electromagnetic hardness of the electronics, a measure of the equipment's resilience to this effect, and the intensity of the field produced by the weapon, the equipment can be irreversibly damaged or in effect electrically destroyed. The damage inflicted is not unlike that experienced through exposure to close proximity lightning strikes, and may require complete replacement of the equipment, or at least substantial portions thereof.

Commercial computer equipment is particularly vulnerable to EMP effects, as it is largely built up of high density Metal Oxide Semiconductor (MOS) devices, which are very sensitive to exposure to high voltage transients. What is significant about MOS devices is that very little energy is required to permanently wound or destroy them, any voltage in excess of tens of Volts can produce an effect termed gate breakdown which effectively destroys the device. Even if the pulse is not powerful enough to produce thermal damage, the power supply in the equipment will readily supply enough energy to complete the destructive process. Wounded devices may still function, but their reliability will be seriously impaired. Shielding electronics by equipment chassis provides only limited protection, as any cables running in and out of the equipment will behave very much like antennae, in effect guiding the high voltage transients into the equipment.

Computers used in data processing systems, communications systems, displays, industrial control applications, including road and rail signalling, and those embedded in military equipment, such as signal processors, electronic flight controls and digital engine control systems, are all potentially vulnerable to the EMP effect.

Other electronic devices and electrical equipment may also be destroyed by the EMP effect. Telecommunications equipment can be highly vulnerable, due to the presence of lengthy copper cables between devices. Receivers of all varieties are particularly sensitive to EMP, as the

highly sensitive miniature high frequency transistors and diodes in such equipment are easily destroyed by exposure to high voltage electrical transients. Therefore radar and electronic warfare equipment, satellite, microwave, UHF, VHF, HF and low band communications equipment and television equipment are all potentially vulnerable to the EMP effect.

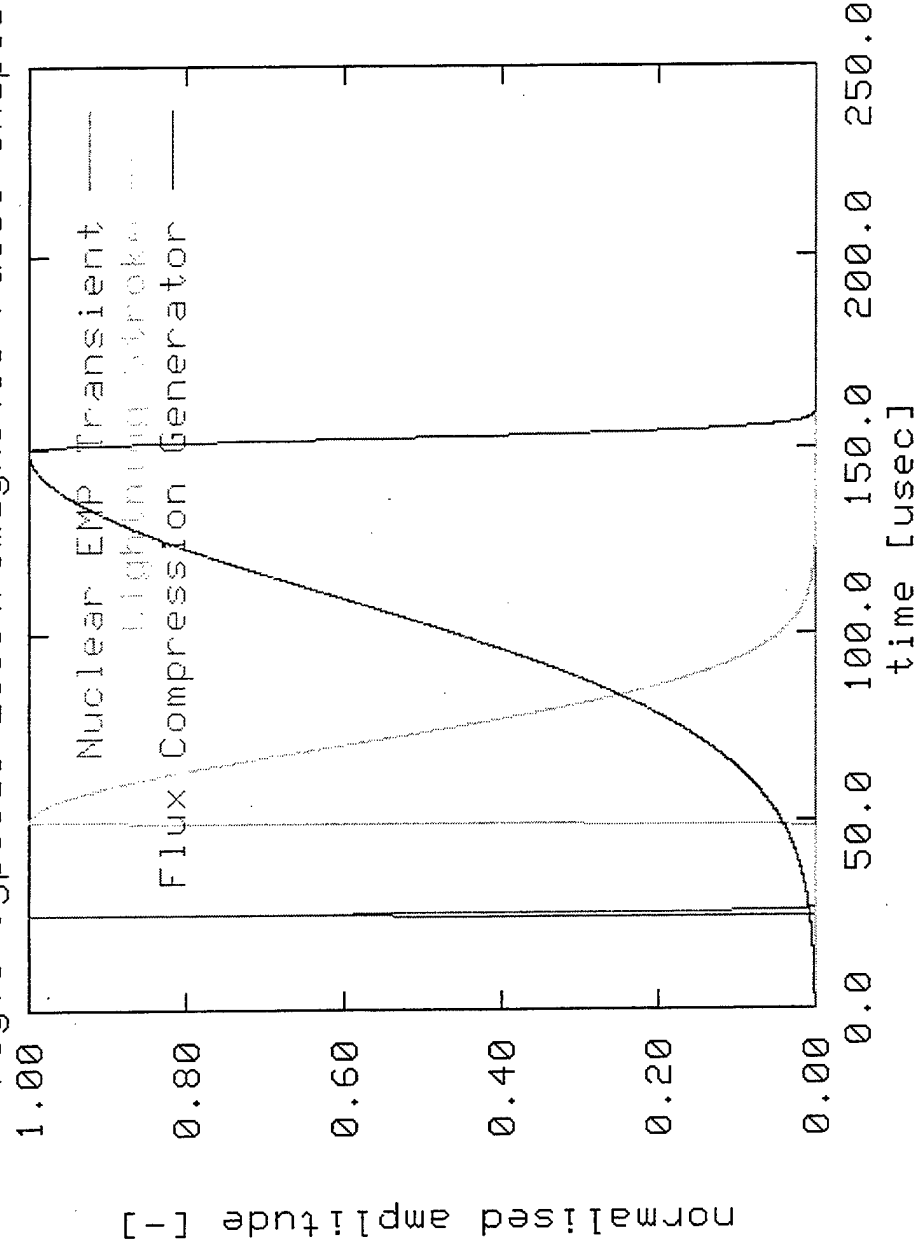
It is significant that modern military platforms are densely packed with electronic equipment, and unless these platforms are well hardened, an EMP device can substantially reduce their function or render them unusable.

### **3. The Technology Base for Conventional Electromagnetic Bombs**

The technology base which may be applied to the design of electromagnetic bombs is both diverse, and in many areas quite mature. Key technologies which are extant in the area are explosively pumped Flux Compression Generators (FCG), explosive or propellant driven Magneto-Hydrodynamic (MHD) generators and a range of HPM devices, the foremost of which is the Virtual Cathode Oscillator or Vircator. A wide range of experimental designs have been tested in these technology areas, and a considerable volume of work has been published in unclassified literature.

This paper will review the basic principles and attributes of these technologies, in relation to bomb and warhead applications. It is stressed that this treatment is not exhaustive, and is only intended to illustrate how the technology base can be adapted to an operationally deployable capability.

Fig.1 Typical Electromagnetic Pulse Shapes



### 3.1. Explosively Pumped Flux Compression Generators

The explosively pumped FCG is the most mature technology applicable to bomb designs. The FCG was first demonstrated by Clarence Fowler at Los Alamos National Laboratories (LANL) in the late fifties [FOWLER60]. Since that time a wide range of FCG configurations has been built and tested, both in the US and the USSR, and more recently CIS.

The FCG is a device capable of producing electrical energies of tens of MegaJoules in tens to hundreds of microseconds of time, in a relatively compact package. With peak power levels of the order of TeraWatts to tens of TeraWatts, FCGs may be used directly, or as one shot pulse power supplies for microwave tubes. To place this in perspective, the current produced by a large FCG is between ten to a thousand times greater than that produced by a typical lightning stroke [WHITE78].

Technical issues in Vircator design are output pulse duration, which is typically of the order of a microsecond and is limited by anode melting, stability of oscillation frequency, often compromised by cavity mode hopping, conversion efficiency and total power output. Coupling power efficiently from the Vircator cavity in modes suitable for a chosen antenna type may also be an issue, given the high power levels involved and thus the potential for electrical breakdown in insulators.

## 4. The Lethality of Electromagnetic Warheads

The issue of electromagnetic weapon lethality is complex. Unlike the technology base for weapon construction, which has been widely published in the open literature, lethality related issues have been published much less frequently.

While the calculation of electromagnetic field strengths achievable at a given radius for a given device design is a straightforward task, determining a kill probability for a given class of target under such conditions is not.

This is for good reasons. The first is that target types are very diverse in their electromagnetic hardness, or ability to resist damage. Equipment which has been intentionally shielded and hardened against electromagnetic attack will withstand orders of magnitude greater field strengths than standard commercially rated equipment. Moreover, various manufacturer's implementations of like types of equipment may vary significantly in hardness due to the idiosyncrasies of specific electrical designs, cabling schemes and chassis/shielding designs used.

The second major problem area in determining lethality is that of coupling efficiency, which is a measure of how much power is transferred from the field produced by the weapon into the target. Only power coupled into the target can cause useful damage.

### 4.1. Coupling Modes

In assessing how power is coupled into targets, two principal coupling modes are recognised in the literature:

(bu Front Door Coupling occurs typically when power from an electromagnetic weapon is coupled into an antenna associated with radar or communications equipment. The antenna subsystem is designed to couple power in and out of the equipment, and thus provides an efficient path for the power flow from the electromagnetic weapon to enter the equipment and cause damage.

(bu Back Door Coupling occurs when the electromagnetic field from a weapon produces large transient currents (termed spikes, when produced by a low frequency weapon ) or electrical standing waves (when produced by an HPM weapon) on fixed electrical wiring and cables interconnecting equipment, or providing connections to mains power or the telephone network [TAYLOR92, WHITE78]. Equipment connected to exposed cables or wiring will experience either high voltage transient spikes or standing waves which can damage power supplies and communications interfaces if these are not hardened. Moreover, should the transient penetrate into the equipment, damage can be done to other devices inside.

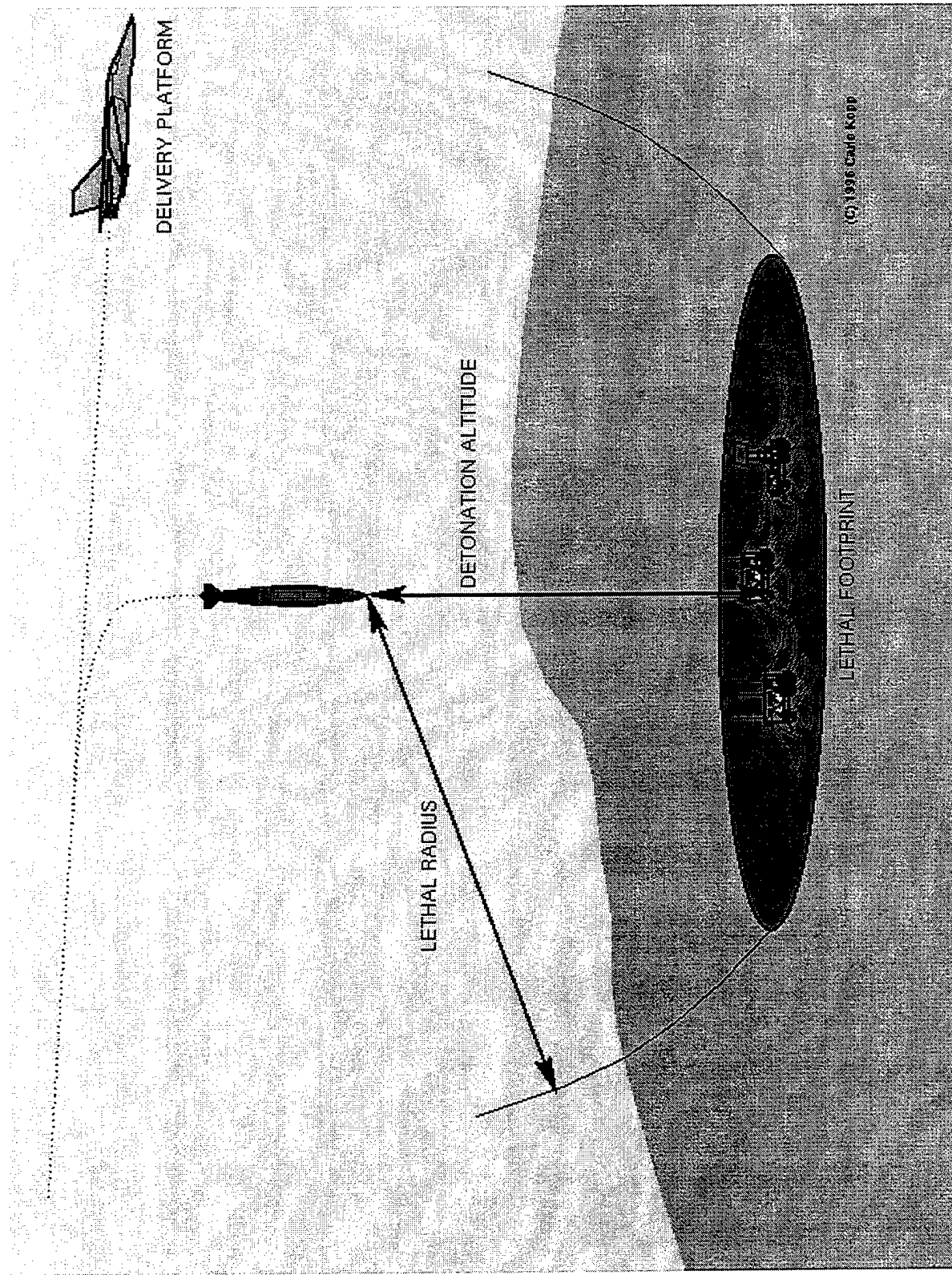


FIG.7 LETHAL FOOTPRINT OF LOW FREQUENCY E- BOMB IN RELATION TO ALTITUDE

The practical constraint is that it may be difficult to produce an efficient high power circularly polarised antenna design which is compact and

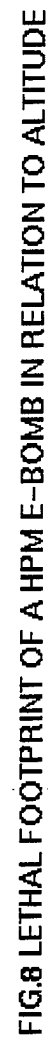
performs over a wide band. Some work therefore needs to be done on tapered helix or conical spiral type antennas capable of handling high power levels, and a suitable interface to a Viricator with multiple extraction ports must be devised. A possible implementation is depicted in Fig.5. In this arrangement, power is coupled from the tube by stubs which directly feed a multi-filar conical helix antenna. An implementation of this scheme would need to address the specific requirements of bandwidth, beamwidth, efficiency of coupling from the tube, while delivering circularly polarised radiation.

Another aspect of electromagnetic bomb lethality is its detonation altitude, and by varying the detonation altitude, a tradeoff may be achieved between the size of the lethal footprint and the intensity of the electromagnetic field in that footprint. This provides the option of sacrificing weapon coverage to achieve kills against targets of greater electromagnetic hardness, for a given bomb size (Fig.7, 8). This is not unlike the use of airburst explosive devices.

In summary, lethality is maximised by maximising power output and the efficiency of energy transfer from the weapon to the target set. Microwave weapons offer the ability to focus nearly all of their energy output into the lethal footprint, and offer the ability to exploit a wider range of coupling modes. Therefore, microwave bombs are the preferred choice.

## 5. Targeting Electromagnetic Bombs

The task of identifying targets for attack with electromagnetic bombs can be complex. Certain categories of target will be very easy to identify and engage. Buildings housing government offices and thus computer equipment, production facilities, military bases and known radar sites and communications nodes are all targets which can be readily identified through conventional photographic, satellite, imaging radar, electronic reconnaissance and humint operations. These targets are typically geographically fixed and thus may be attacked providing that the aircraft can penetrate to weapon release range. With the accuracy inherent in GPS/inertially guided weapons, the electromagnetic bomb can be programmed to detonate at the optimal position to inflict a maximum of electrical damage.



Mobile and camouflaged targets which radiate overtly can also be readily engaged. Mobile and relocatable air defence equipment, mobile



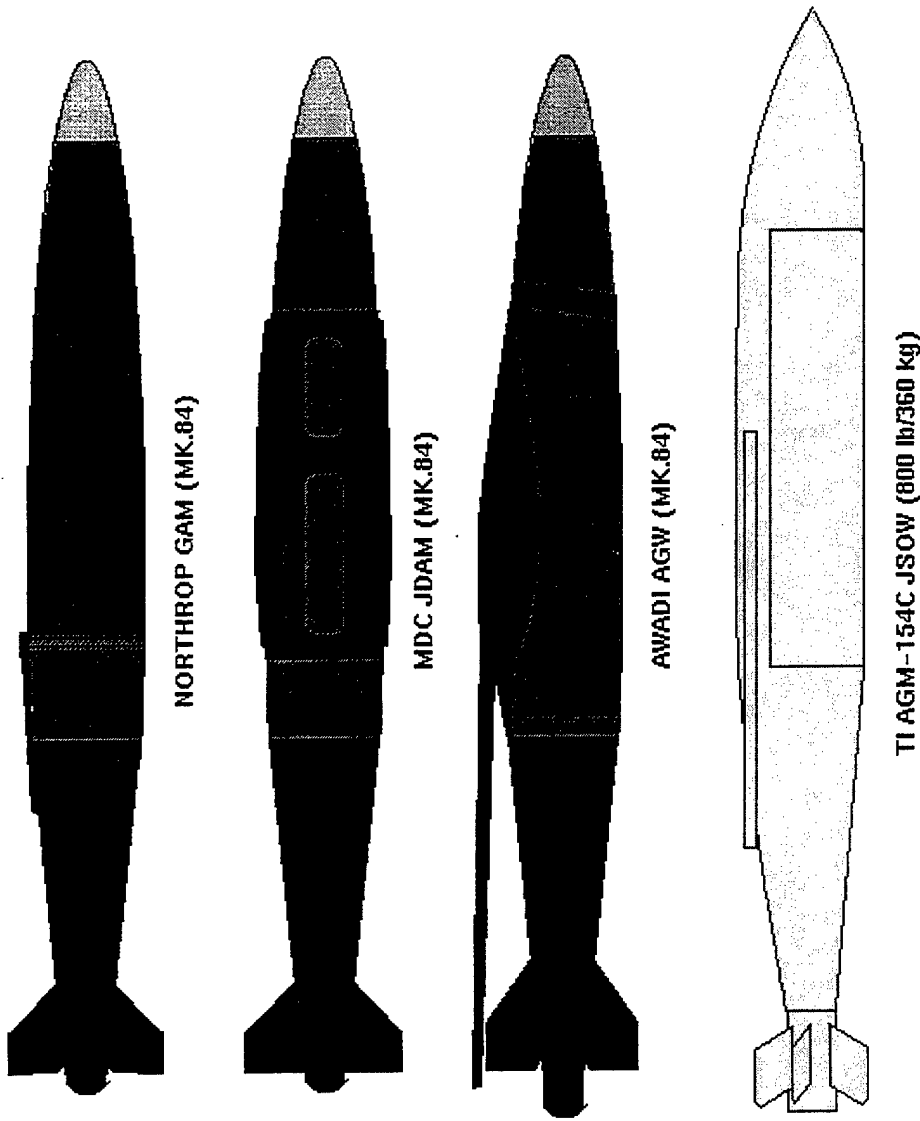
communications nodes and naval vessels are all good examples of this category of target. While radiating, their positions can be precisely tracked with suitable Electronic Support Measures (ESM) and Emitter Locating Systems (ELS) carried either by the launch platform or a remote surveillance platform. In the latter instance target coordinates can be continuously datalinked to the launch platform. As most such targets move relatively slowly, they are unlikely to escape the footprint of the electromagnetic bomb during the weapon's flight time.

Mobile or hidden targets which do not overtly radiate may present a problem, particularly should conventional means of targeting be employed. A technical solution to this problem does however exist, for many types of target. This solution is the detection and tracking of Unintentional Emission (UE) [HERSKOWITZ96]. UE has attracted most attention in the context of TEMPEST [3] surveillance, where transient emanations leaking out from equipment due poor shielding can be detected and in many instances demodulated to recover useful intelligence. Termed Van Eck radiation [VECK85], such emissions can only be suppressed by rigorous shielding and emission control techniques, such as are employed in TEMPEST rated equipment.

Whilst the demodulation of UE can be a technically difficult task to perform well, in the context of targeting electromagnetic bombs this problem does not arise. To target such an emitter for attack requires only the ability to identify the type of emission and thus target type, and to isolate its position with sufficient accuracy to deliver the bomb. Because the emissions from computer monitors, peripherals, processor equipment, switchmode power supplies, electrical motors, internal combustion engine ignition systems, variable duty cycle electrical power controllers (thyristor or triac based), superheterodyne receiver local oscillators and computer networking cables are all distinct in their frequencies and modulations, a suitable Emitter Locating System can be designed to detect, identify and track such sources of emission.

A good precedent for this targeting paradigm exists. During the SEA (Vietnam) conflict the United States Air Force (USAF) operated a number of night interdiction gunships which used direction finding receivers to track the emissions from vehicle ignition systems. Once a truck was identified and tracked, the gunship would engage it [4].





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**FIG.9 GPS GUIDED BOMB/GLIDEBOMB KITS**

Because UE occurs at relatively low power levels, the use of this detection method prior to the outbreak of hostilities can be difficult, as it may be necessary to overfly hostile territory to find signals of usable intensity [5]. The use of stealthy reconnaissance aircraft or long range, stealthy Unmanned Aerial Vehicles (UAV) may be required. The latter also raises the possibility of autonomous electromagnetic warhead armed expendable UAVs, fitted with appropriate homing receivers. These would be programmed to loiter in a target area until a suitable emitter is detected, upon which the UAV would home in and expend itself against the target.

## 6. The Delivery of Conventional Electromagnetic Bombs

As with explosive warheads, electromagnetic warheads will occupy a volume of physical space and will also have some given mass (weight) determined by the density of the internal hardware. Like explosive warheads, electromagnetic warheads may be fitted to a range of delivery vehicles.

Known existing applications [6] involve fitting an electromagnetic warhead to a cruise missile airframe. The choice of a cruise missile airframe will restrict the weight of the weapon to about 340 kg (750 lb), although some sacrifice in airframe fuel capacity could see this size increased. A limitation in all such applications is the need to carry an electrical energy storage device, eg a battery, to provide the current used to charge the capacitors used to prime the FCG prior to its discharge. Therefore the available payload capacity will be split between the electrical storage and the weapon itself.

In wholly autonomous weapons such as cruise missiles, the size of the priming current source and its battery may well impose important limitations on weapon capability. Air delivered bombs, which have a flight time between tens of seconds to minutes, could be built to exploit the launch aircraft's power systems. In such a bomb design, the bomb's capacitor bank can be charged by the launch aircraft enroute to target, and after release a much smaller onboard power supply could be used to maintain the charge in the priming source prior to weapon initiation.

An electromagnetic bomb delivered by a conventional aircraft [7] can offer a much better ratio of electromagnetic device mass to total bomb mass, as most of the bomb mass can be dedicated to the electromagnetic device installation itself. It follows therefore, that for a given technology an electromagnetic bomb of identical mass to a electromagnetic warhead equipped missile can have a much greater lethality, assuming equal accuracy of delivery and technologically similar electromagnetic device design.

A missile borne electromagnetic warhead installation will comprise the electromagnetic device, an electrical energy converter, and an onboard storage device such as a battery. As the weapon is pumped, the battery is drained. The electromagnetic device will be detonated by the missile's onboard fusing system. In a cruise missile, this will be tied to the navigation system; in an anti-shipping missile the radar seeker and in an air-to-air missile, the proximity fusing system. The warhead fraction (ie ratio of total payload (warhead) mass to launch mass of the weapon) will be between 15% and 30% [8].

An electromagnetic bomb warhead will comprise an electromagnetic device, an electrical energy converter and a energy storage device to pump and sustain the electromagnetic device charge after separation from the delivery platform. Fusing could be provided by a radar altimeter fuse to airburst the bomb, a barometric fuse or in GPS/inertially guided bombs, the navigation system. The warhead fraction could be as high as 85%, with most of the usable mass occupied by the electromagnetic device and its supporting hardware.

Due to the potentially large lethal radius of an electromagnetic device, compared to an explosive device of similar mass, standoff delivery would be prudent. Whilst this is an inherent characteristic of weapons such as cruise missiles, potential applications of these devices to glidebombs, anti-shipping missiles and air-to-air missiles would dictate fire and forget guidance of the appropriate variety, to allow the launching aircraft to gain adequate separation of several miles before warhead detonation.

The recent advent of GPS satellite navigation guidance kits for conventional bombs and glidebombs has provided the optimal means for cheaply

delivering such weapons. While GPS guided weapons without differential GPS enhancements may lack the pinpoint accuracy of laser or television guided munitions, they are still quite accurate (CEP (~40 ft) and importantly, cheap, autonomous all weather weapons.

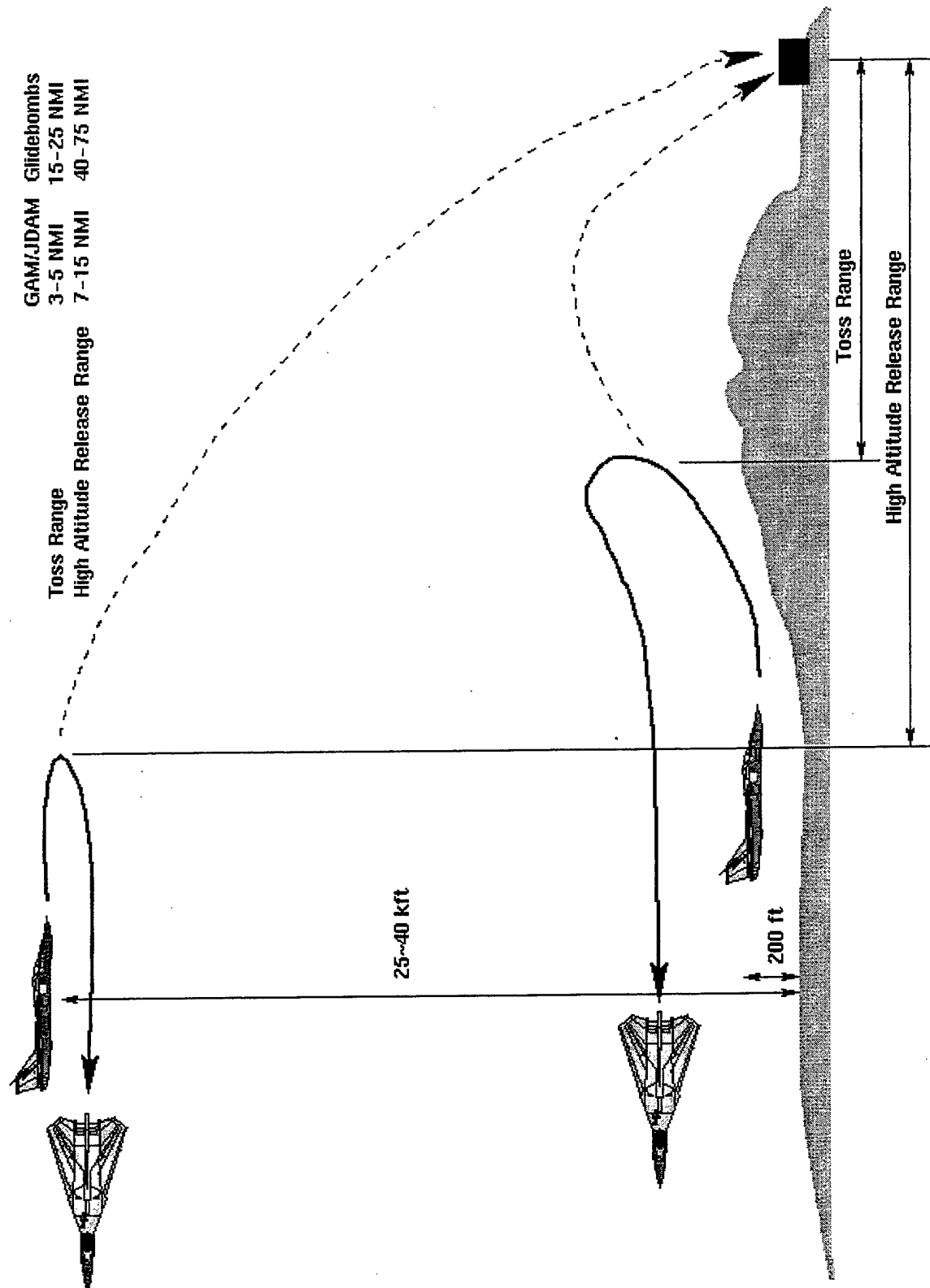


FIG.10 DELIVERY PROFILES FOR GPS/INERTIAL GUIDED WEAPONS

The USAF has recently deployed the Northrop GAM (GPS Aided Munition) on the B-2 bomber [NORTHROP95], and will by the end of the decade deploy the GPS/inertially guided GBU-29/30 JDAM (Joint Direct Attack Munition)[MDC95] and the AGM-154 JSOW (Joint Stand Off Weapon) [PERGLER94] glidebomb. Other countries are also developing this technology, the Australian BAeA AGW (Agile Glide Weapon) glidebomb achieving a glide range of about 140 km (75 nmi) when launched from altitude [KOPP96].

The importance of glidebombs as delivery means for HPM warheads is threefold. Firstly, the glidebomb can be released from outside effective radius of target air defences, therefore minimising the risk to the launch aircraft. Secondly, the large standoff range means that the aircraft can remain well clear of the bomb's effects. Finally the bomb's autopilot may be programmed to shape the terminal trajectory of the weapon, such that a target may be engaged from the most suitable altitude and aspect.

A major advantage of using electromagnetic bombs is that they may be delivered by any tactical aircraft with a nav-attack system capable of delivering GPS guided munitions. As we can expect GPS guided munitions to become the standard weapon in use by Western air forces by the end of this decade, every aircraft capable of delivering a standard guided munition also becomes a potential delivery vehicle for a electromagnetic bomb. Should weapon ballistic properties be identical to the standard weapon, no software changes to the aircraft would be required.

Because of the simplicity of electromagnetic bombs in comparison with weapons such as Anti Radiation Missiles (ARM), it is not unreasonable to expect that these should be both cheaper to manufacture, and easier to support in the field, thus allowing for more substantial weapon stocks. In turn this makes saturation attacks a much more viable proposition.

## 7. Defence Against Electromagnetic Bombs

The most effective defence against electromagnetic bombs is to prevent their delivery by destroying the launch platform or delivery vehicle, as is the case with nuclear weapons. This however may not always be possible, and therefore systems which can be expected to suffer exposure to the electromagnetic weapons effects must be electromagnetically hardened.

The most effective method is to wholly contain the equipment in an electrically conductive enclosure, termed a Faraday cage, which prevents the electromagnetic field from gaining access to the protected equipment. However, most such equipment must communicate with and be fed with power from the outside world, and this can provide entry points via which electrical transients may enter the enclosure and effect damage. While optical fibres address this requirement for transferring data in and out, electrical power feeds remain an ongoing vulnerability.

Another situation where electromagnetic bombs may find useful application is in dealing with governments which actively implement a policy of state sponsored terrorism or info-terrorism, or alternately choose to conduct a sustained low intensity land warfare campaign. Again the Strategy of Graduated Response, using electromagnetic bombs in the initial phases, would place the government under significant pressure to concede.

As a punitive weapon electromagnetic devices are attractive for dealing with belligerent governments. Substantial economic, military and political damage may be inflicted with a modest commitment of resources by their users, and without politically damaging loss of life.

## 11. Conclusions

Electromagnetic bombs are Weapons of Electrical Mass Destruction with applications across a broad spectrum of targets, spanning both the strategic and tactical. As such their use offers a very high payoff in attacking the fundamental information processing and communication facilities of a target system. The massed application of these weapons will produce substantial paralysis in any target system, thus providing a decisive advantage in the conduct of Electronic Combat, Offensive Counter Air and Strategic Air Attack.

Because E-bombs can cause hard electrical kills over larger areas than conventional explosive weapons of similar mass, they offer substantial economies in force size for a given level of inflicted damage, and are thus a potent force multiplier for appropriate target sets.

The non-lethal nature of electromagnetic weapons makes their use far less politically damaging than that of conventional munitions, and therefore broadens the range of military options available.

This paper has included a discussion of the technical, operational and targeting aspects of using such weapons, as no historical experience exists as yet upon which to build a doctrinal model. The immaturity of this weapons technology limits the scope of this discussion, and many potential areas of application have intentionally not been discussed. The ongoing technological evolution of this family of weapons will clarify the relationship between weapon size and lethality, thus producing further applications and areas for study.

E-bombs can be an affordable force multiplier for military forces which are under post Cold War pressures to reduce force sizes, increasing both their combat potential and political utility in resolving disputes. Given the potentially high payoff deriving from the use of these devices, it is incumbent upon such military forces to appreciate both the offensive and defensive implications of this technology. It is also incumbent upon governments and private industry to consider the implications of the proliferation of this technology, and take measures to safeguard their vital assets from possible future attack. Those who choose not to may become losers in any future wars.

## 12. Acknowledgements

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- Carlo Kopp is one of Australia's foremost proponents of Information Warfare. Born in Perth, Western Australia, he graduated with first class honours in Electrical Engineering in 1984, from the University of Western Australia. In 1996 he completed an MSc in Computer Science and is currently working on a PhD in the same discipline, at Monash University in Melbourne, Australia. He has over a decade of diverse industry experience, including the design of high speed communications equipment, optical fibre receivers and transmitters, communications equipment including embedded code, Unix computer workstation motherboards, graphics adaptors and chassis. More recently, he has consulted in Unix systems programming, performance engineering and system administration. Actively publishing as a defence analyst in Australia's leading aviation trade journal, Australian Aviation, since 1980, he has become a locally recognised authority on the application of modern military



technology to operations and strategy. His work on electronic combat doctrine, electromagnetic weapons doctrine, laser remote sensing and signature reduction has been published by the Royal Australian Air Force since 1992.

- 1 Electromagnetic pulse or EMP device is a generic term applied to any device, nuclear or conventional, which is capable of generating a very intense but short electromagnetic field transient. For weapons applications, this transient must be sufficiently intense to produce electromagnetic power densities which are lethal to electronic and electrical equipment. Electromagnetic weapons are electromagnetic devices specifically designed as weapons. Whilst the terms 'conventional EMP weapon' and 'High Power Microwave or HPM weapon' have been used interchangeably in trade journals (see FULGHUM93), this paper will distinguish between microwave band and low frequency weapons. The term 'electromagnetic bomb' or 'E-bomb' will be used to describe both microwave and low frequency non-nuclear bombs. This paper will not address the use of nuclear EMP, or alternate uses of HPM technology. HPM technology has a broad range of potential applications in EW, radar and directed energy weapons (DEW). The general conclusions of this paper in the areas of infrastructure vulnerability and hardening are also true for microwave directed energy weapons. This paper extends the scope of earlier work by the author on this subject [KOPPP93].
- 2 - One bizarre instance of lightning strike electrical damage was described to the author by an eyewitness technician, tasked with assessing the damage on the site. A lightning bolt impacted in the close vicinity of a transmitter shed. RF and power cables ran from the transmitter shed to a transmission tower through a rectangular, metal shielded tunnel. The effect of the lightning strike was to produce an electromagnetic standing wave in the tunnel, much like in a microwave waveguide. All cables within the tunnel were burned through at regular spacings along the tunnel, corresponding precisely to the half wavelength of the standing wave in the tunnel.
- 3 The NACSIM 5100A standard specifies acceptable emission levels for TEMPEST (Transient ElectroMagnetic Pulse Emanation Standard) rated equipment.
- 4 The Northrop/Lockheed ASD-5 Black Crow DF receiver was fitted to the AC-130A Pave Pronto gunships, rebuilt from obsolete C-130 transports [ICH10].
- 5 A noteworthy technical issue in this context is that even equipment not-rated to TEMPEST standards will radiate energy at very low power levels, in comparison with intentional transmissions by radar or communications equipment. A receiver designed to detect, identify and locate sources of UE radiation will either need to be highly sensitive, or deployed very close to the emitter. It is worth noting that UE from computer monitors and networks exhibit known regular patterns, and correlation techniques could be used to significantly improve receiver sensitivity [DIXON84].
- 6 Fulghum D.A., ALCMs Given Non Lethal Role, AW&ST, Feb 22, 1993. This recent report indicates that the US has progressed significantly with its development work on electromagnetic warhead technology. An electromagnetic warhead was fitted to the USAF AGM-86 Air Launched Cruise Missile airframe, involving both structural and guidance system modifications. The description in this report suggests the use of an explosive pumped flux generator feeding a device such as a Viricator. References to magnetic coils almost certainly relate to the flux compression generator hardware.
- 7 The Journal of Electronic Defence [JED96] recently reported on the USAF Phillips Laboratory at Kirtland awarding a \$6.6M HPM SEAD

weapon technology demonstration program contract to Hughes Missile Systems Co. This contract will see Hughes conduct design studies in order to define design goals, and then fabricate brassboard demonstration hardware using government developed technology. JED speculate that the weapon will be a FCG driven microwave tube, which is most likely the case given the USAF's prior research activities in this area [REINOVSKY85]. An earlier report [JED95] indicated the existence of a related program which addresses command and control warfare and counter-air capabilities. In any event, the devices produced by these programs are likely to become the first operationally fielded HPM electromagnetic bombs for delivery by combat aircraft.

8 This may be readily determined by calculating the ratio of warhead mass to total weapon launch mass, for representative missile types. Taking the AGM-78 Standard as a lower limit yields 15.9%, whereas taking the AGM/BGM-109 Tomahawk as an upper limit yields about 28%. Figures are derived from manufacturers' brochures and reference publications eg Jane's Air-Launched Weapons.

9 Staines, Fulghum. This is entirely consistent with theoretical expectations, as the different spectral characteristics of microwave electromagnetic warheads, compared to nuclear electromagnetic weapons, will significantly affect the effectiveness of protective filters. What is important from an electrical engineering viewpoint is that a filter designed to stop signals in the lower frequency bands may perform very poorly at microwave frequencies.

10 See International Countermeasures Handbook, 14th Edition, pp 104.

11 Gary Waters, Gulf Lesson One. Chapter 16 of this reference provides a good discussion of both the rationale and implementation of this strategy.

12 Soft kill means will inhibit or degrade the function of a target system during their application, leaving the target system electrically and physically intact upon the cessation of their application. Hard kill means will damage or destroy the target system, and are thus a means of inflicting attrition.

13 - this is also the stated intent of the USAF HPM SEAD technology demonstration program. The fact that the first application of a HPM bomb is electronic combat underscores the tactical, operational and strategic importance of first defeating an air defence system when prosecuting a strategic air war.

14 The classical argument here is centred upon Allied experience in bombing Germany during WW2, where even repeated raids on industrial targets were unable to wholly stop production, and in many instances only served to reduce the rate of increase in production. What must not be overlooked is that both the accuracy and lethality of weapons in this period bore little comparison to what is available today, and automation of production facilities was almost non-existent.

15 This constraint primarily results from limitations in numbers. Strategic air attack requires precision delivery of substantial payloads, and is thus most effectively performed with specialised bomber assets, such as the B-52, B-1, B-2, F-111, F-15E, F-117A, Tornado or Su-24. These are typically more maintenance intensive than less complex multirole fighters, and this will become a constraint to the sortie rate achievable with a finite number of aircraft, assuming the availability of aircrew. Whilst multirole fighters may be applied to strategic air attack, their typically

lesser payload radius performance and lesser accuracy will reduce their effectiveness. In the doctrinal context, this can be directly related to existing USAF aerospace doctrine [AFM1-1], in several areas.

Download the [power point presentation](#) (zipped 195K) by Carlo Kopp on "The E-Bomb- a Weapon of Electrical Mass Destruction."

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## **Section A-5: Angel of Death--UAV's**

# SAF/PA 96-1204 UAV *Technologies and Combat Operations* Executive Summary

This document has been cleared by SAF/PA Cleared for open publication on 6 Dec 96 SAF/PA 96-1204UAV

This summary is a product of the United States Air Force Scientific Advisory Board Study on *UAV Technologies and Combat Operations*. Statements, opinions, recommendations and conclusions contained in this report are those of the study members and do not necessarily represent the official position of the USAF or the Department of Defense.

## Introduction

The Air Force has entered a new era, an era in which the unmanned aerial vehicle (UAV) has become not only acceptable, but desirable, for long-endurance reconnaissance missions. It is timely then, for the Air Force Scientific Advisory Board (SAB) to review technology maturity in the context of accepted Air Force mission tasks and to project new UAV mission tasks-both combat and noncombat-that might be enabled by available and forecast technologies. Thus, the Air Force Chief of Staff directed the 1996 study "UAV Technologies and Combat Operations."

The study report includes a Summary Volume (Volume I) and a Volume that includes the individual Panel reports (Volume II). The Summary Volume deals first with the mission task concepts, then the platform considerations that bound the air vehicle parameters, then the system/sub-system elements (i.e., mission systems and weapons), and finally, the human factors considerations. An example point design-a Suppression of Enemy Air Defenses (SEAD) UAV with a roadmap for programmatic accomplishment-is provided along with a recommendation that a SEAD demonstration program be pursued. Some special subjects are presented, followed by overall recommendations and concluding remarks. The reader is referred to Volume II to more completely understand the approach and deliberations in the specific areas, and to discern a more complete set of conclusions and recommendations. Additionally, some issues for which complete study was beyond the scope of, or time available in this study are also presented in Volume II.

## Findings

The study group identified a number of findings relative to the application of UAVs to Air Force roles and missions:

1. *UAVs have significant potential to enhance the ability of the Air Force to project combat power in the air war.*

2. *UAVs have the ability (range, persistence, survivability, and altitude) to provide significant surveillance and observation data economically, compared with current manned aircraft approaches.*
3. *UAVs have the potential to accomplish tasks that are now, for either survivability or other reasons, difficult for manned aircraft including counterair (cratering runways and attacking aircraft shelters), destroying or functionally killing chemical warfare/biological warfare (CW/BW) manufacturing and storage facilities, and suppression of enemy air defenses.*
4. *UAVs can be weaponized in the near-term<sup>1</sup> (perhaps using advanced versions of the Tier vehicles), using an existing weapon and hypervelocity kinetic energy penetrators with a family of warheads.*
5. *Insufficient emphasis has been placed on human systems issues. Particularly deficient are applications of systematic approaches to allocating functions between humans and automation, and the application of human factors principles in system design.*
6. *Most other technologies necessary for platforms, propulsion, avionics, and mission systems are sufficiently mature to provide initial UAV capabilities of the nature described above. Further technology development can significantly enhance these capabilities.*
7. *New warhead technologies-namely intermetallic high temperature self-propagating synthesis reaction incendiary and "flying plate" concepts- can provide the UAV the ability to deliver compact weapons capable of inflicting devastating damage to a large number of fixed and moving targets.*
8. *Little thought has been given to appropriate responses to enemy use of UAVs, particularly those armed with air-to-air missiles.*

In order to fully exploit the potential of UAVs, the Air Force must think of them as new and complete systems with new combinations of advantages and disadvantages, rather than as vehicles with a single outstanding characteristic or as a slight variant of an existing vehicle. Thus, advances must be made across the board, including concepts of operation, platform, weapon, mission systems technologies, and especially, human systems.

### **Operational Mission and Mission Task Concepts**

The study group assessed UAV contributions to Air Force missions and promulgated 22 missions/tasks to which UAVs can contribute. The following nine missions are representative of UAV mission needs and serve as a context in which to address technology opportunities. In no particular order, they are:

- Counter Weapons of Mass Destruction
- Theater Missile Defense-Ballistic Missiles/ Cruise Missiles
- Fixed Target Attack
- Moving Target Attack

## Jamming Suppression of Enemy Air Defenses Intelligence, Surveillance, and Reconnaissance Communications/Navigation Support Air-to-Air

The study analyzed each of these missions in terms of operational capability and ability to exploit the enabling technologies. Platforms, propulsion, mission systems, and weapons were considered, as were human factors aspects. Challenges were identified and programs were suggested. The Air Force is encouraged to consider these and other missions in more detail and to establish programs in those that, after further analysis, are determined to be appropriate.

The Air Force should also be on a continual lookout for new or non-traditional missions, some of which may complement existing roles (e.g., use of UAVs as the "eyes" for B-52s, thus averting costly B-52 upgrades) and new missions that may leverage technology advances (e.g., seeding and monitoring unattended ground sensors).

## Demonstrations

The introduction of UAVs into the Air Force operational and organizational structure is considered an evolutionary process, highly dependent on a series of operational demonstrations of which the current Predator, DarkStar, and Global Hawk programs are part. These demonstrations are key to developing technical and operational confidence in UAVs. Specifically, the Air Force has the opportunity for near-term demonstrations in the following mission/task areas:

1. *Enhanced ISR missions with electronic support measures (ESM), foliage penetration, and advanced radar sensors, coupled with automatic target cueing or screening, and advanced fusion concepts,*
2. *ESM and jamming payloads for detection, precision location, and neutralization of radio frequency emitting threats,*
3. *Fixed and moving target attack using UAVs to detect and locate targets based on image-coordinate transformation, cueing, and advanced lightweight weapons,*
4. *Communications and navigation support, based on the Defense Advanced Research Projects Agency (DARPA) UAV Communications Node concept, but adding Global Positioning System (GPS) augmentation pseudolites for precision guidance under GPS jamming,*
5. *Suppression of enemy air defenses.*

## Recommendations

The study Panel made numerous detailed recommendations which are found in Volume II. The major recommendations are outlined below, with

more detail on each provided in Chapter 11 of this Volume.

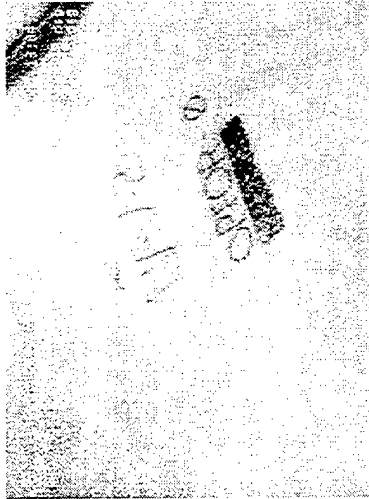
1. *Take the lead role in programs to exploit the near-term UAVs (Predator, DarkStar, and Global Hawk) in Air Force, Joint and National roles.*
2. *Pursue the SEAD mission as an early application of UAVs in an attack role.*
3. *Initiate a program, perhaps with DARPA, that leads to the development and deployment of advanced penetrating combat UAVs in the mid- to far- term.*
4. *Increase emphasis on effective techniques for flight management and employment of UAVs.*
5. *Establish UAV experimental capabilities to address crew-vehicle flight management concepts and increase emphasis on human system related topics in development programs.*
6. *Expand work in engines, air vehicle structures, and flight management technologies.*
7. *Supplement avionics and mission systems technology base programs in mission system automation, miniaturization, and sensor aperture areas critical to UAV operations.*
8. *Initiate a modular weapons and warhead program specifically oriented to the mission tasks most suited to UAVs.*
9. *Initiate a broad program to address opportunities for dramatically reducing operations and support costs for UAVs.*
10. *Promote command, control, communications, and intelligence (C3I) architectures that consider UAVs in the context of the overall Joint Forces structure.*
11. *Develop systems, concepts, and processes for UAV airspace management and deconfliction.*
12. *The study group adopted the use of near-term (1996-2005), mid-term (2005-2015), and far-term (2015-2025) as the periods in which initial operational demonstrations could occur.*

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<sup>1</sup>The study group adopted the use of near-term (1996-2005), mid-term (2005-2015), and far-term (2015-2025) as the periods in which initial operational demonstrations could occur.



# Unmanned Air Vehicles



UAVs hold great potential for civil, commercial, and military use. Without having to engineer aircraft around the human body, UAVs allow for revolutionary changes in the way we design aircraft. In the next forty years we can expect to see UAVs moving into every field of aviation. Below are listed a few of the most recognized UAVs in the civil and military fields.

## Dark Star

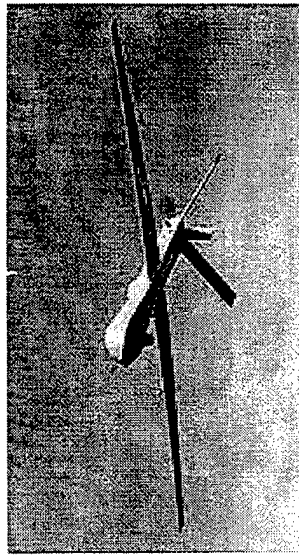


Above View

Mission (ft.)	Acq./ recon./surv.	Length (ft.)	15
Powerplant	1 x William Rolls Fj44 tf	Wingspan (ft.)	65
Playload Type	SAR	Body Dia. (ft.)	12
Speed (mph.)	288+	Weight (lb.)	8600
Endurance (hrs. or mi.)	8 hr.+	Max. Altitude (ft.)	45,000

Lockheed Martin Skunk Works project developed with Boeing. The elaborate Tier 3- Dark Star suffered a setback in 1996 with the crash of its first prototype. Such a UAV is intended to bridge the gap between the small tactical UAVs and reconnaissance satellites. Design utilizes many stealth features

# Predator

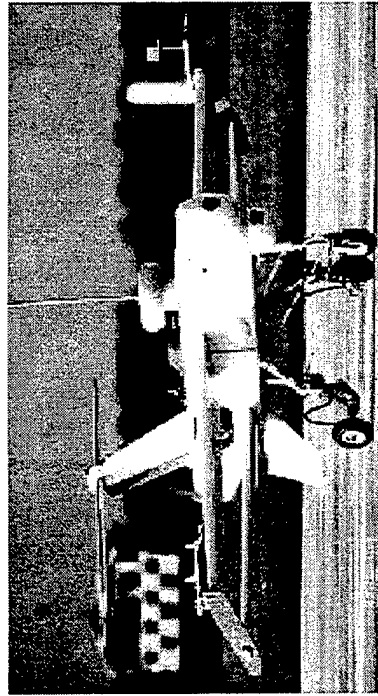


Ground Station

Mission (ft.)	Recon./surv./target	Length (ft.)	28
Powerplant	1 x Rotax 912 gasoline	Wingspan (ft.)	48
Playload Type	Day TV, FLIR, SAR	Body Dia. (ft.)	2.5
Speed (mph.)	65-80	Weight (lb.)	2300
Endurance (hrs. or mi.)	23 hr.	Max. Altitude (ft.)	25,000

General Atomics UAV in service around the world. The success of the Predator in Bosnia has attracted favorable U.S. Congressional attention, leading to additional funding for U.S. UAV programs. In early 1996, a Predator GPS flight control system returned it to its base in Hungary- even after the command link was lost over Bosnia.

# Outrider

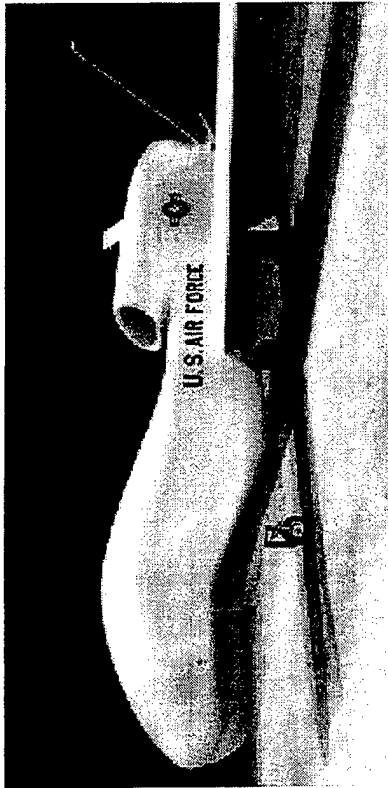


Cut-away view

Mission (ft.)	Multipurpose	Length (ft.)	9.9
Powerplant	Heavy fuel engine	Wingspan (ft.)	11.2
Payload Type	EO/IR	Body Dia. (ft.)	1
Speed (mph.)	126	Weight (lb.)	385
Endurance (hrs. or mi.)	4.9 hr.	Max. Altitude (ft.)	15,000

Tactical UAV selected by the Army, Marines, and Navy. Deployable from land or shipdeck. Auto takeoff and landing.

## Global Hawk



Mission (ft.)	Recon.	Length (ft.)	44.4
Powerplant	1x Allison AE3007H tf.	Wingspan (ft.)	116
Payload Type	- by Hughes	Body Dia. (ft.)	4.8
Speed (mph.)	395	Weight (lb.)	24,000
Endurance (hrs. or mi.)	42 hr./ 16,566 mi.	Max. Altitude (ft.)	67,000

Still in development. This UAV is meant to fly a very aggressive flight plan and carry out missions performed before by aircraft such as the SR-71.



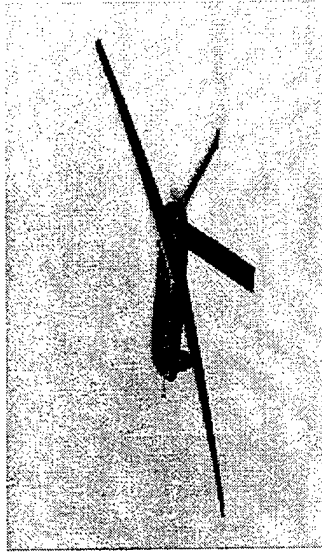
## Scorpion 100

Mission (ft.)	Multipurpose	Length (ft.)	11.8
Powerplant	1x Rotax 50 hp.	Wingspan (ft.)	16.1
Payload Type	Day/night E/O; 50 lb.	Body Dia. (ft.)	1.7
Speed (mph.)	173	Weight (lb.)	321
Endurance (hrs. or mi.)	3-5 hr.	Max. Altitude (ft.)	15,000

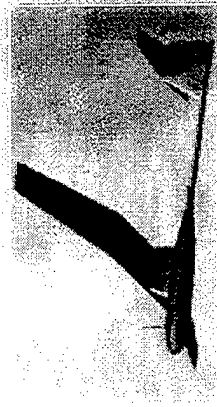


## Prowler

Mission (ft.)	Recon./surv./target	Length (ft.)	11.1
Powerplant	1x Norton NR731	Wingspan (ft.)	18.1
Payload Type	Day TV, E/O, IR	Body Dia. (ft.)	1.8
Speed (mph.)	184	Weight (lb.)	200
Endurance (hrs. or mi.)	8 hr.+	Max. Altitude (ft.)	20,000

**Gnat**

Mission (ft.)	Recon./surv./target	Length (ft.)
Powerplant	1 x Rotax 912 gasoline	Wingspan (ft.)
Playload Type	Day TV, Flir	Body Dia. (ft.)
Speed (mph.)	201	Weight (lb.)
Endurance (hrs. or mi.)	60 hr.	Max. Altitude (ft.)
Exported to Turkey.		

**Pointer**

Mission (ft.)	Multipurpose/recon.	Length (ft.)
Powerplant	1 x Astro 15 elec.	Wingspan (ft.)
Playload Type	Day/IR sensors	Body Dia. (ft.)
Speed (mph.)		-

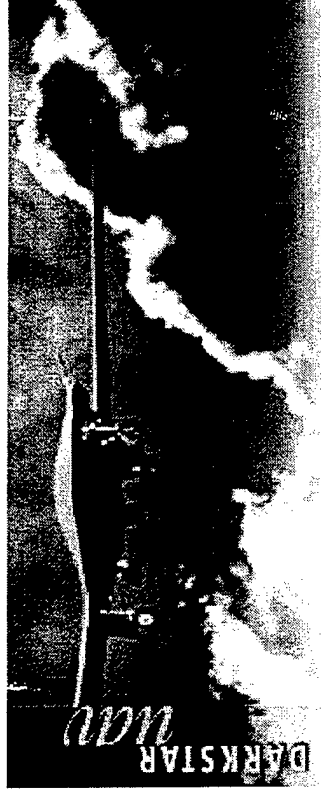
## PRODUCT

## UAV EAGLE EYE

## UAV

12/19/97 Press Release03/02/98 Press Release

This Eagle Eye® Tiltrotor Unmanned Air Vehicle (UAV) can take off or land anywhere, without the need of a runway. Maximum speed: 200 kts, 370 kph. Range (sea level): Radius of Action after one hour on station - 500 nm, 925 km.



electronics/  
information systems

## DarkStar UAV

The DarkStar unmanned aerial vehicle, a prototype developed by the team of Boeing and Lockheed Martin Skunk Works, successfully completed its first flight on Friday, March 29, 1996. The 20-minute flight took off from Edwards Air Force Base, Calif., at 6:25 a.m. (PST). DarkStar reached an altitude of 5,000 feet and completed basic flight maneuvers.

Boeing and Lockheed Martin are developing the low-observable, high-altitude UAV -- with a fuselage length of 15 feet and a wingspan of 69 feet -- for the Department of Defense. Powered by a single turbofan engine, it can operate at ranges greater than 500 nautical miles and loiter for more than eight hours at altitudes greater than 45,000 feet. DarkStar's mission will be to penetrate aggressively defended airspace.

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Boeing Home | Military Airplanes

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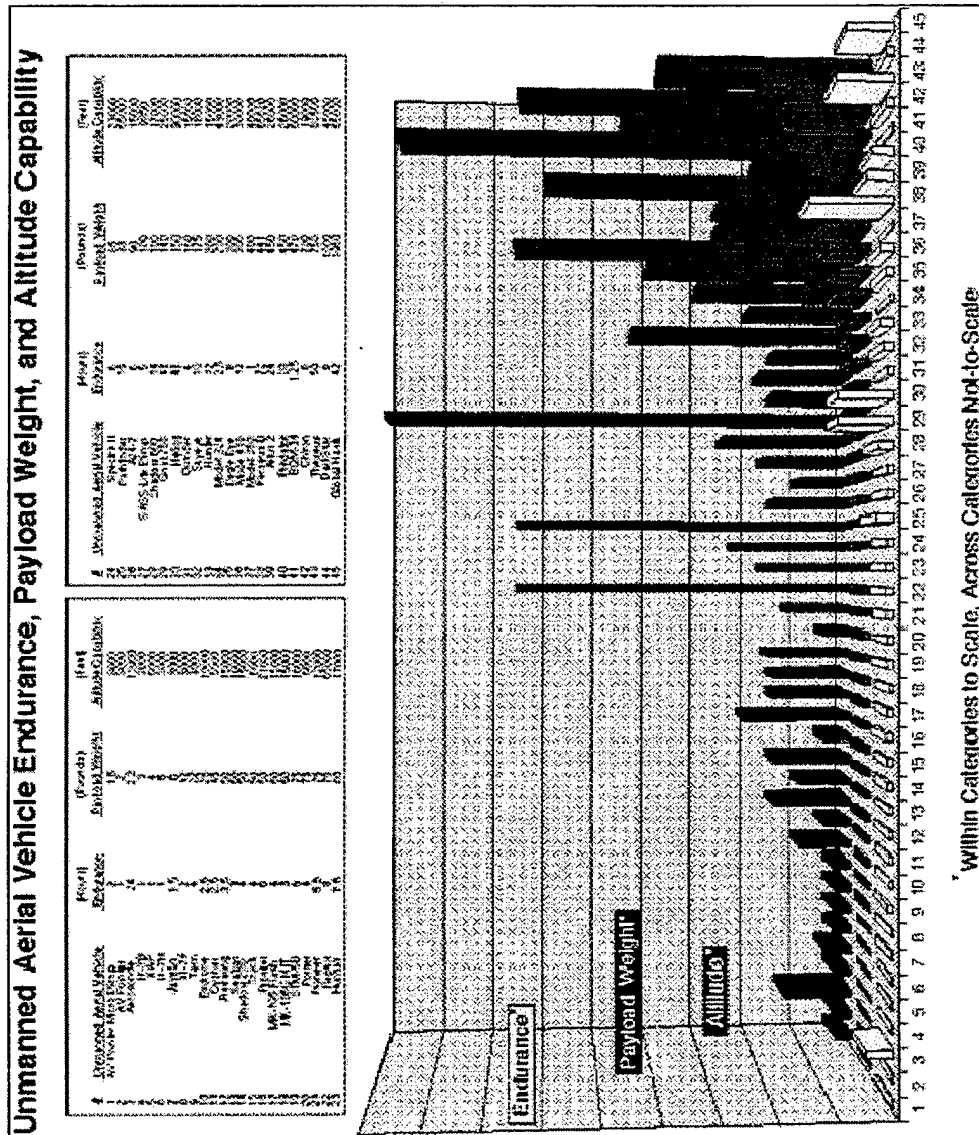
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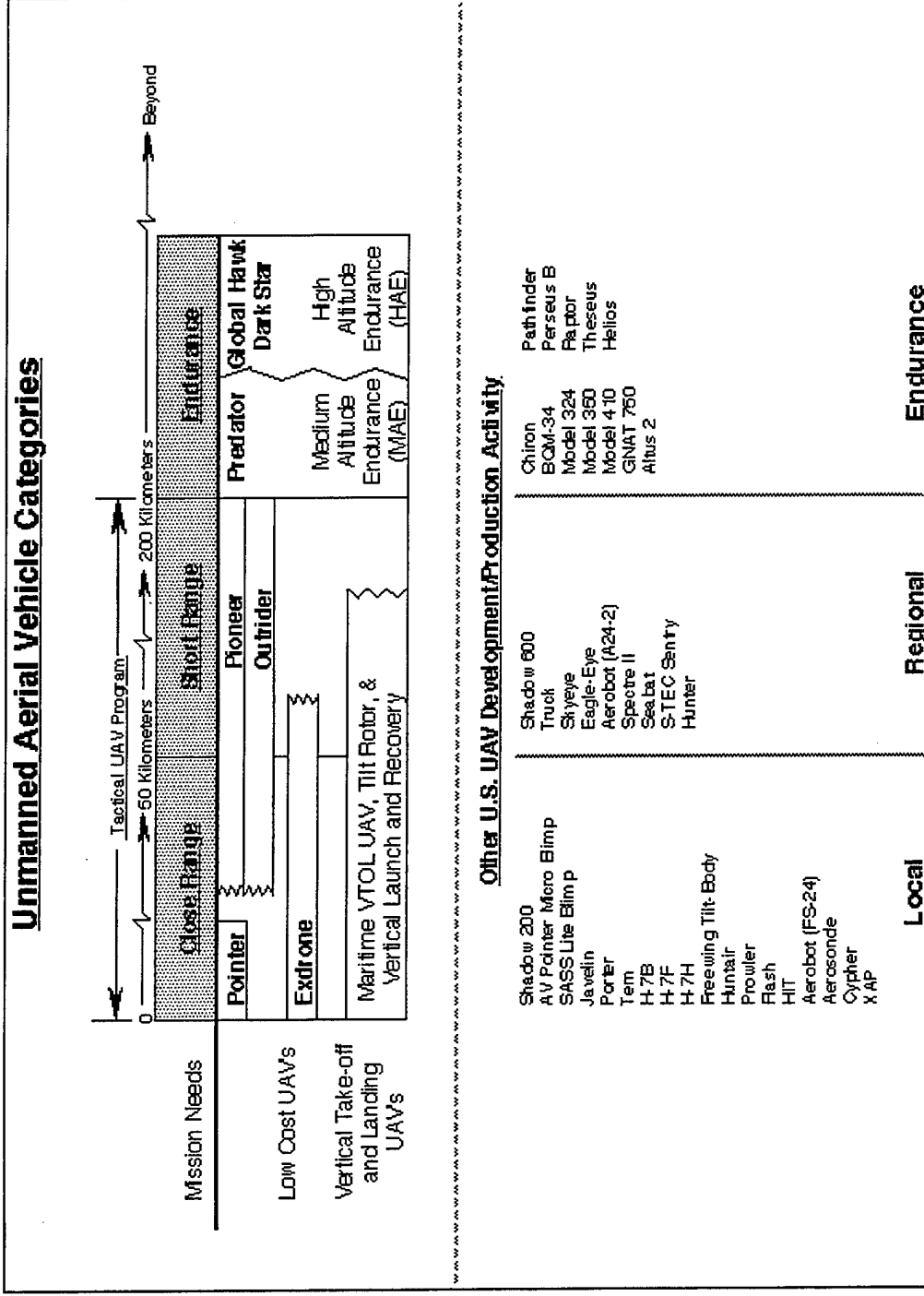
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## UAV Characteristics Database

Click on the name of a UAV to display the characteristics for that vehicle.

Unmanned Aerial Vehicle Name	Endurance (Hours)	Payload Weight (Pounds)	Altitude Capability (Feet)	Costing Info
<a href="#">AV Pointer</a>	1 hr.	2 lbs.	3,000 ft.	Yes
<a href="#">AV Pointer Micro Blimp</a>	2 hrs.	1.5 lbs.	3,000 ft.	Yes
<a href="#">Aerobot</a>	n/a	n/a	n/a	-
<a href="#">Aerosonde</a>	24 hrs.	2.2 lbs.	13,000 ft.	Yes
<a href="#">Altus 2</a>	24 hrs.	450 lbs.	26,000 ft.	Yes
<a href="#">BQM-34</a>	1.25 hrs.	470 lbs.	60,000 ft.	Yes
<a href="#">Chiron</a>	8 hrs.	700 lbs.	19,000 ft.	-
<a href="#">Cypher</a>	2.5 hrs.	45 lbs.	5,000 ft.	-
<a href="#">Darkstar</a>	8 hrs.	1,000 lbs.	45,000 ft.	Yes
<a href="#">Eagle Eye</a>	8 hrs.	300 lbs.	20,000 ft.	-
<a href="#">Exdrone</a>	2.5 hr.	25 lbs.	10,000 ft.	-
<a href="#">Firebee</a>	1.25 hrs.	470 lbs.	60,000 ft.	-
<a href="#">Freewing</a>	3.5 hrs.	50 lbs.	15,000 ft.	-
<a href="#">Global Hawk</a>	42 hrs.	1,960 lbs.	65,000 ft.	Yes
<a href="#">Gnat 750</a>	48 hrs.	140 lbs.	25,000 ft.	Yes
<a href="#">Hawk-i 7B</a>	1 hr.	3 lbs.	3,000 ft.	Yes
<a href="#">Hawk-i 7F</a>	2 hrs.	12 lbs.	3,000 ft.	Yes
<a href="#">Hawk-i 7H</a>	1 hr.	5 lbs.	3,000 ft.	Yes
<a href="#">Huntair</a>	7.5 hrs.	80 lbs.	17,000 ft.	Yes
<a href="#">Hunter</a>	12 hrs.	200 lbs.	15,000 ft.	-
<a href="#">Javelin</a>	1.5 hrs.	6 lbs.	3,000 ft.	-
<a href="#">Model 324</a>	2.5 hrs.	200 lbs.	43,000 ft.	-
<a href="#">Model 350</a>	1 hr.	400 lbs.	40,000 ft.	-
<a href="#">Model 410</a>	12 hrs.	300 lbs.	30,000 ft.	-
<a href="#">Outrider</a>	4 hrs.	160 lbs.	15,000 ft.	Yes
<a href="#">Pathfinder</a>	16 hrs.	88 lbs.	70,000 ft.	-
<a href="#">Perseus B</a>	72 hrs.	441 lbs.	65,620 ft.	-
<a href="#">Pioneer</a>	5.5 hrs.	75 lbs.	12,000 ft.	Yes
<a href="#">Porter</a>	4 hrs.	75 lbs.	5,000 ft.	Yes
<a href="#">Predator</a>	20 hrs.	450 lbs.	26,000 ft.	Yes
<a href="#">Prowler</a>	6 hrs.	50 lbs.	21,000 ft.	-
<a href="#">Raptor</a>	8 hrs.	75 lbs.	65,000 ft.	-
<a href="#">SASS Lite</a>	5 hrs.	100 lbs.	9,850 ft.	-
<a href="#">STM-5B</a>	6 hrs.	75 lbs.	16,000 ft.	-
<a href="#">Seabat</a>	3 hrs.	50 lbs.	10,000 ft.	-

<u>Shadow 200</u>	4 hrs.	50 lbs.	15,000 ft.	-
<u>Shadow 600</u>	14 hrs.	100 lbs.	17,000 ft.	-
<u>Skyeye</u>	10 hrs.	175 lbs.	18,000 ft.	-
<u>Spectre II</u>	6 hrs.	85 lbs.	23,000 ft.	-
<u>Tern</u>	4 hrs.	22 lbs.	3,000 ft.	-
<u>Theseus</u>	50 hrs.	750 lbs.	88,500 ft.	-
<u>Truck</u>	4 hrs.	50 lbs.	5,000 ft.	Yes

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Edit the UAV Database (Restricted Access).

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## **Section A-6: Network of Destruction-- IWAM's**

## Weapon Systems

Dominate the Maneuver Battle

# Wide Area Munition (WAM)



**MISSION:** The mission of the Wide Area Munition (WAM) is to counter the enemy's mobility. It will delay, disrupt and canalize enemy vehicle movement in the close battle. Future variants will perform these functions in deep battle.

**CHARACTERISTICS:** The WAM is the Army's first generation of a smart, autonomous top attack munition. It employs seismic and acoustic sensors to detect, classify and track a target. Once the target is validated by internal control electronics and within the 100 meter lethal radius, the munition determines the optimum firing point and launches a submunition over the target. The sublet acquires the target by infrared sensor and fires a tantalum explosively formed penetrator (EFP) at the top of the target vehicle.

**FOREIGN COUNTERPARTS:** None known.

**PROGRAM STATUS:** The WAM is currently in EMD. Milestone IIIa is scheduled for 4QFY95, Milestone III is scheduled for 4QFY96.

**PROJECTED ACTIVITIES:** Critical Design Review is scheduled for March 1995.

LRIP contract is planned for a 2QFY96 award.

TT/UT will be completed by 4QFY96.

**PRIME CONTRACTOR:** Textron Defense Systems (Wilmington, MA)

**SUBCONTRACTORS:**

Hughes; Fullerton, CA

Opto-Electronics; Petaluma, CA

Mason and Hanger; Burlington, IA

Textron Defense System; Wilmington, MA

Eagle Picher; Joplin, MO

Texas Instruments; Dallas, TX

Hercules; Rocket City, WV

## *Systems Fielded or in Production*

TACOM-ARDEC is a world leader in munitions technologies and providing state-of-the-art systems to its customers - the soldiers in the field. The following descriptions illustrate some of TACOM-ARDEC's most successful systems and detail the weapon systems which TACOM-ARDEC has helped to put into the field.

- [Sense and Destroy Armor \(SADARM\) Projectile, 155mm](#)
  - [Wide Area Munition \(WAM\)](#)
  - [Mortar Systems](#)
  - [M829A1 "Silver Bullet", 120mm Tank Cartridge](#)
  - [M830A1 HEAT \(High Explosive Anti-Tank\)](#)
  - [M109A6 "Paladin", Self-Propelled Howitzer](#)
  - [M712 "Copperhead" Projectile, 155mm](#)
  - [MK19 Mod3 40mm Grenade Machine Gun](#)
  - [M16A2 Semiautomatic Rifle](#)
  - ["Volcano" Mine Dispenser](#)
  - [M864 DPICM Artillery Projectile, 155mm](#)
- 

- **SADARM (Sense and Destroy Armor)** is a 155mm artillery projectile designed to attack armored vehicles, especially self-propelled howitzers. Rounds containing two SADARM submunitions are launched to within the submunition's attack footprint; separating from the carrier, the submunitions descend on parachutes and detect and identify priority targets using infrared and millimeter-wave sensors and onboard computers. At the appropriate standoff, the submunition detonates, forming an EFP which destroys the target by attacking the relatively weak top armor.



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- **WAM (Wide Area Munition)** consists of three major subsystems:

- a communications module,
- a ground platform module, and
- a smart submunition/warhead (sublet) module.

Once deployed, the WAM uprights itself and autonomously searches for a target vehicle. WAM uses acoustic and seismic sensors to locate, identify and track armored targets. When a firing solution is satisfied, the WAM launches a sublet in a trajectory over the target. The sublet uses a passive infrared sensor to detect the target and fires an Explosively Formed Penetrator (EFP) at the vulnerable area. In addition, the WAM has a command destruct capability for easy battlefield cleanup. WAM is currently planned for hand-emplacement with the potential for a deep attack, indirect fire delivered variant in the future.

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- TACOM-ARDEC is a world leader in the design and development of **Mortar Systems**. Under the direction of Project Manager, Mortars, TACOM-ARDEC has fielded many systems including the 60mm Lightweight Company Mortar System, the improved 81mm Mortar System, and a 120mm Battalion Mortar System. Some of TACOM-ARDEC's most notable accomplishments are the 81mm blast attenuation device, which allows the mortar to be fired at longer ranges by reducing blast overpressure near the crew; the 60mm and 81mm

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# The Hornet: A Wide-Area Munition

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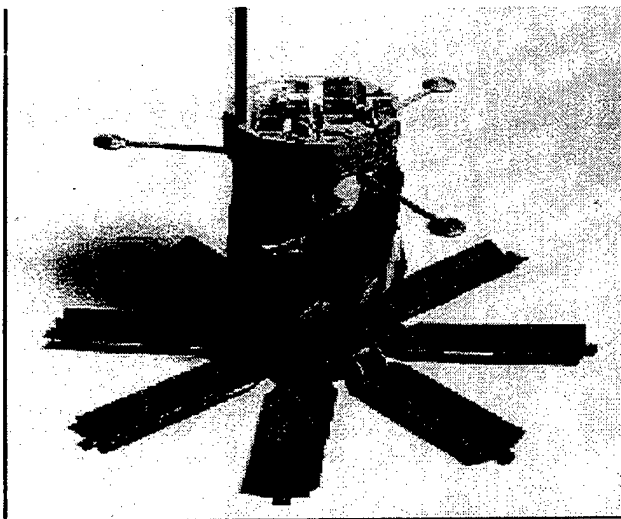
*By Major Gregory Fields*

The Army recently completed development of the world's first wide-area munition (WAM). The M93 hand-emplaced WAM, popularly known as the Hornet, fulfills the Army's need for a lethal, deployable munition that will defeat armored vehicles at and beyond direct-fire ranges. The Hornet is the first in a family of Hornet derivatives that will change the way engineers fight and how we will influence the battle.

The Hornet program began in 1986 with a Department of the Army message. A required operational capability document was approved in 1990 that outlined a prioritized, three-phased WAM development plan: (1) deep-attack, (2) hand-emplaced, and (3) Volcano-emplaced. With the collapse of the Soviet Union and the rise in importance of early-entry operations, the priority was changed to (1) hand-emplaced, (2) hand-emplaced with two-way communication and redeployability, and (3) deep-attack.

Initially, contracts were awarded to two contractors. Alliant Techsystems' WAM prototype was based on the sense and destroy armor (SADARM) artillery warhead. Textron Defense Systems' prototype was based on their U.S. Air Force extended-range antiarmor munition proto-type. Textron won a 1990 competition and is now the sole contractor. They are continuing development and testing, with type classification scheduled for 3rd quarter FY96.

The Hornet is about to enter low-rate production and will be fielded at Fort Bragg beginning in July 1998.



The Hornet

## How the Hornet Works

The Hornet is a 35-pound munition designed to detect, identify, track, engage, and defeat moving targets up to T-80 class tanks at ranges up to 100 meters. It can be armed manually or remotely by the M71 Modular Pack Mine System remote control unit.

Before emplacement, the soldier removes the Hornet's active battery from the shipping container and inserts it for circuit testing. The Hornet comes with the main reserve cell battery embedded in the munition, and it is not activated until final arming. Also before emplacement, manual or remote arming is determined, the target switch is set (to attack only heavy, tracked vehicles, or all tracked vehicles), and a self-destruct time is selected. The four standard family of scatterable mines self-destruct times (4 hours, 48 hours, 5 days, or 15 days) are available, as well as a 30-day self-destruct time.

The soldier exits the area after emplacing and throwing the arm-enable switch and before the end of the safe separation time. For manual arming, the safe separation time is 5-6 minutes, after which time the Hornet will automatically arm. For remote arming, the safe separation time is 30-36 minutes. At the end of the safe separation time (either manual or remote), micro-detonators sever the cable holding the Hornet's eight legs in place, and the munition snaps upright. This visual cue (a Hornet with legs deployed) indicates that it is armed or at least no longer safe to approach. A remote arm command may be sent up to 60 days after the arm-enable switch is thrown.

An armed Hornet goes to power cycling "sleep" mode until the geophone seismic sensor detects a potential target, usually at ranges of up to 600 meters. This alerts the munition to start listening with its three microphones, which are also deployed at legs-down. The Hornet tracks the two loudest noise sources it hears and attacks the louder of the two when it reaches the closest point of approach to the munition.

Before the Hornet attacks, ground platform electronics go through a sophisticated analysis and decision process to ensure the submunition is properly pro-programmed to engage the target. It determines if the target is moving left-to-right or right-to-left, is wheeled or tracked, and is heavy or light. (The Hornet does not engage targets under 5 metric tons.) Hornets currently attack only tracked vehicles, but follow-on variants will engage heavy, wheeled vehicles as well. If the target is a tank, the Hornet determines if it is a diesel or turbine tank, and if it is a Russian-style tank with the exhaust port over the left rear deck. In each case, the hot spot that the submunition's infrared sensor sees is at a different offset from the engine deck (rear for diesel, left rear for Russian, and in the exhaust plume for a turbine).

Properly programmed, the submunition launches like a skeet at a 30-degree angle. It precesses (wobbles) as it flies out so it can scan the ground in overlapping circles. Fly-out time to the 100-meter range is about 3-4 seconds. Once over the target, the sub-munition fires its explosively formed penetrator warhead at the appropriate offset from the vehicle hot spot to achieve a mobility kill. The warhead can penetrate any vehicle on the rear deck and most on the turret roof.



## Not a Mine

The Hornet began as a sophisticated off-route, reinforcing mine. But after study, it became clear that it was more correctly a short-range, autonomous antiarmor system—a robot with a shoulder-fired anti-tank weapon. The difference is explained below.

The original Hornet concept was to kill breaching vehicles as they led an attack through conventional or scatterable minefields. Hornets would be laid in front of these minefields to achieve this effect. The TRADOC Analysis Command confirmed this as useful but also identified better uses.

In a march to contact or meeting engagement situation, an enemy force will use roads to maximize speed. Hornets employed in clusters of 3-6 munitions will disrupt this movement by causing casualties and



throwing off timing and coordination. This tactic is called the *gauntlet*. One refinement is to switch deeper gauntlet clusters to detonate tanks only, so lighter reconnaissance vehicles will falsely report the route as clear. Once committed to the route, tanks encounter these clusters while the reconnaissance vehicles encounter attacks by later clusters. A second refinement is to use this tactic in conjunction with the layout of the road network to influence the enemy commander's route selection. This use elevates engineer operations to the direct attack of enemy planning and execution at regimental and divisional echelons.

A third use of the Hornet was determined in modeling at the U.S. Army Engineer School by examining enemy movements between his approach march and assault formations. At 5 kilometers or one terrain feature from our positions, Russian doctrine requires regiments and battalions to change from column of march to column of companies and column of platoons. In this scenario, Hornets are laid in a large "X" pattern (a kilometer on each side) to disrupt this prebattle activity as the enemy changes formations (see figure). This causes casualties and confusion at a critical timing point in the area where the regimental artillery group will set up to support the attack.

These uses of the Hornet are impossible (or logistically prohibitive) for conventional and scatterable mines. And while the Hornet can be used to install a linear obstacle, the munition's 100-meter range is as much of a liability as an asset. When one enemy vehicle breaks clear of a minefield, it might leave a 4-meter path; but when one enemy vehicle clears a WAM obstacle, it clears a much wider swath.



The Hornet undergoes extensive development testing at Yuma Proving Ground, Arizona, to sub design responsibility.

## Characteristics

The Hornet is a first-generation, autonomous, smart antiarmor munition. Its unique capabilities allow it to be employed in a variety of missions:

### *Performance.*

- Attacks valid targets to ranges of 100 meters, and any target approaching within 15 meters.
- Can be placed on slopes of up to 15 degrees on almost any soil and surface type.

### *Other Characteristics.*

- Contains no explosives in the ground-platform modules. Launch is by a chemical gas generator. If disturbed, the Hornet will quick-fire and the sublet will detonate immediately on launch. In all cases, the ground-platform electronics will burn themselves out on launch to preclude intelligence use if captured.
- Can be transported by truck, ship, or aircraft. It is externally transportable by helicopter but is not yet certified for airdrop. A single C-141 aircraft can carry 1,080 Hornets.
- Is survivable in severe climatic and chemical environments and is not affected by a high-altitude electromagnetic pulse. The Hornet is certified decontaminable only before removal from its storage container.
- Can operate in all weather conditions. However, its sensors are somewhat affected by weather conditions, such as rain, snow, and very heavy fog, that weaken sound and thermal signatures.

## Training and Doctrine

Beginning in 1997, the combat training centers will receive the M97 collective training device. In 1998, the M93 hand-emplaced WAM will be fielded, and the training support centers will receive the M98 individual training device. The M98s will be fielded in sets of 20 to support platoon-level training on the emplacement of multiple gauntlet clusters and single-area disruption patterns. Squads can emplace individual gauntlet clusters, but emplacing multiple gauntlet clusters and single-area disruption patterns is a platoon mission.

Hornet emplacement will be a 12B10 common task. Institutional training for soldiers and leaders will begin in FY97. Supervisory tasks will be taught in the Basic Noncommissioned Officer Course, while leaders will learn Hornet tactics, techniques, and procedures in the Engineer Officer Basic and Advanced Courses.

The following doctrinal publications will be revised to include Hornet information: FM 20-32, *Mine/Countermine Operations*; FM 90-7, *Combined Arms Obstacle Integration*; FM 5-100, *Engineer Operations*; and FM 5-71-100, *Division Engineer Combat Operations*.

Command and control measures will parallel those required for hand-emplaced mines. Final decisions will depend on Standardized North Atlantic Treaty Organization Agreements (STANAGs) currently under discussion. The draft STANAG requires a form similar to the DA Form 1355 that shows the position of each Hornet and an outline of the 100-meter lethal area(s) encompassed by them. Emplacement authority resides at Corps until delegated.

## The Future

Development has begun on the product improvement program (PIP) Hornet. The PIP adds two-way communication over a single-channel, ground-to-air radio system (SINCGARS) to an Army common hardware computer control unit, with a line-of-sight range of 3-5 kilometers. The PIP Hornet can be turned off and queried to confirm its status. If the legs aren't deployed, it can be picked up and moved to a new location. If they are deployed, the Hornet reports every target it hears to the control unit. Prior to launch, it reports the type of target it is about to attack. A preplanned PIP for a repeater to extend the communication range is scheduled for 4-8 years after fielding of the PIP Hornet.

Development of the intelligent minefield (IMF) begins in 1998. The IMF program will add an acoustic

overwatch sensor, long-haul communication capability, and local computer control to the emplaced Hornets to coordinate such actions as when and what targets to engage.

An IMF can report the individual targets identified by the Hornets, approaching aircraft and personnel, and the composition and direction of enemy formations. An IMF can wait until the middle of a column to attack, and can call for reinforcing fires. It can also adjust these fires for maximum effect. Employed autonomously, the IMF can participate in counterreconnaissance, guard open flanks, or cover tactical risk areas. When emplaced deep, the IMF can cue deep strikes by artillery or air, adjust artillery fires, and report subsequent enemy presence to assess battle damage or cue follow-on strikes. Development of a dedicated deep-attack WAM variant will begin in 2000.

The Hornet is the Corps of Engineers' premier munition system. It gives maneuver commanders greater flexibility on the battlefield, allowing engineers to better support the countermobility mission. The Hornet helps to free overtasked engineer resources for more efficient use on high-priority combat missions. In short, the Hornet provides U.S. forces with a significant advantage over opposing forces. It can support and influence direct- and indirect-fire battles as well as influence enemy decision-making, timetables, and maneuver at the regimental and divisional levels. The Hornet adds another dimension to the battlefield and expands the parameters of control and influence that affect the flow of battle.

*Major Fields is the chief of the Mines Branch, TRADOC System Manager, Engineer Combat Systems. Previous assignments include Facility Construction Research and Development Officer and Assistant Project Manager for the Sense and Destroy Armor (SADARM) Program, both at Picatinny Arsenal, New Jersey. A graduate of the Command and General Staff College, Major Fields holds a bachelor of science degree in mechanical engineering from Alabama Agricultural and Mechanical University and a bachelor of science in aerospace engineering from Georgia Institute of Technology.*

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[eubanksc@wood.army.mil](mailto:eubanksc@wood.army.mil)

## DEFENSE TECHNOLOGY AREA PLAN DTOs WEAPONS

**WE.02.07 Land Mines.** This DTO will develop and demonstrate an affordable, rapidly deployable land mine system for early entry operations with 50% greater kill probability against armor vehicles. To achieve this objective, the Intelligence Minefield (IMF) ATD will internet wide area munitions (WAMs) and advanced acoustic sensors into an autonomous antiarmor/antivehicle system by demonstrating communication, command, and control; sensor fusion of acoustic sensor data; autonomous implementation of engagement tactics; advanced acoustic sensors; and exportable combat and target information. In FY97, the IMF ATD will demonstrate (through field test and simulation/modeling) an integrated IMF system that will internet WAMs and advanced acoustic sensors to increase WAM minefield effectiveness. The advanced acoustic sensors will have a detection range of 2-3 km and a tracking capability of up to seven target vehicles. Also demonstrated will be a control station that will communicate, command, and control two minefields consisting of 20-40 WAMs while maintaining an interface to the maneuver command system. The RFPI ACTD field exercise will take place in FY98.

Metrics include a 50-100% improvement in overall minefield performance; a 2-3-km minimum range acoustic detection; a 7+ target tracking; and a robustness criteria for ACTD residuals. Technical barriers include target association and classification, target location accuracy, and real-time target information processing.

### Service/Agency POC

Mr. Gregory Colombo  
ARDEC-IMF ATD Mgr  
(201) 724-3353  
Fax (201) 724-2501  
DSN 880-3353

### USD(A&T) POC

Dr. C. W. Kitchens, Jr.  
DDR&E/WT  
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Kitchecw@acq.osd.mil

### Customer POC

Mr. Eric McGrath (Lead)  
US Army Engineer School  
(573) 563-4085  
Fax (573) 563-4089

### Programmed DTO Funding (\$ millions)

PE	Project	FY97	FY98	FY99	FY00	FY01	FY02	FY03
0603004A	DL95	2.2	0	0	0	0	0	0
<b>Total</b>		2.2	0	0	0	0	0	0

**WE.04.04 Airborne Lasers for Theater Missile Defense.** This DTO will develop and demonstrate technology for development of an operational high-energy airborne laser (ABL) for theater missile defense (TMD). It will address risk reduction issues for development of the ABL demonstrator and the subsequent development of an ABL system with full operational capability. Key technical challenges include development of laser device technology to meet the weight and volume constraints of the aircraft platform, and development of adaptive optics and beam control technology to substantially compensate for optical distortions and beam jitter introduced in the ABL propagation scenario. To address these challenges, this technology program investigates and demonstrates atmospheric propagation over long

## Family of Wide Area Munitions (WAM)

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**DESCRIPTION:** We will develop WAM in three sequential phases:

1. Basic Hand emplaced (HE-WAM)
2. HE-WAM product improved with a remote control on/off/on capability (HE-WAM PIP)
3. A deep attack version (DA-WAM, delivered by rocket, missile or fixed wing aircraft.

The WAM, common to all variants, has standoff detection and engagement capability. It attacks targets from the top at ranges of up to 100 meters and provides a mobility kill. The basic HE-WAM engages tracked armored vehicles, and may be armed manually or by the M71 MOPMS Remote Control Unit (RCU). The HE-WAM PIP will engage tracked and wheeled vehicles, be remotely controlled by the CIRCE RCU, and can be recovered and redeployed prior to initial arming.

**STATUS:** HE-WAM completed a successful live fire test against a moving T-62 tank on 1 May 92. The basic HE-WAM is in Engineering and Manufacturing Development (EMD). A low rate production decision is scheduled for 4QFY95, with first unit equipped scheduled for 2QFY98. The HE-WAM PIP will enter EMD 1QFY96, with first unit equipped scheduled for 2QFY01.

**EMPLOYMENT CONCEPT:** WAM can be used in offensive and defensive operations and in both a tactical and operational role. In the close battle, HE-WAM will be emplaced by combat engineers, maneuver forces under engineer supervision, and at extended ranges by Special Operations Forces and Rangers. WAM gauntlets, a series of randomly spaced clusters of 3-6 WAMs, will be employed along high speed avenues of approach to disrupt and attrite the enemy. WAM area disruption obstacles, consisting of 20 WAMs employed in an "X" pattern across a grid square, will disrupt and attrite the enemy as he moves cross country prior to the start of the direct fire battle. When employed deep, WAM will disrupt a threat commander's operational tempo by attacking his follow-on forces, logistics, C2, by denying key terrain such as approaches to bridges/river crossing sites, and by selectively attacking high value targets, such as Tactical Ballistic Missile (TBM) launchers.

**BASIS OF ISSUE:** WAM is a Class V item.

**TRAINING/PERSONNEL:** USAES will provide training on the employment of WAM. Individual and collective trainers are being procured to train operator tasks and for force-on-force training.

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IEEE

## UNITED STATES ACTIVITIES BOARD

## POSITION STATEMENT

Promoting Career and Technology Policy Interests of Electrical, Electronics and Computer Engineers

\*\*\*\*\*

## THE SAFETY OF ELECTROMAGNETIC PULSE SIMULATORS

As Approved by the IEEE United States Activities Board  
May 1992

\*\*\*\*\*

Electromagnetic Pulse (EMP) simulators are used to evaluate potential damage to electronic systems from intense, pulsed electromagnetic fields. These simulators generate very brief, single pulses of intense, electromagnetic (EM) fields that are confined to the immediate vicinity of the simulator. For many years, questions concerning the safety of exposures to EMP fields have been raised by various groups (including EMP simulator workers, environmental activists and the general public). Members of our committee, experts in the engineering and biological issues associated with EMP fields, have evaluated the engineering, physics, and biomedical literature on the bioeffects of brief, intense pulsed electromagnetic fields.

Studies of laboratory animals that were exposed to millions of EMP simulator pulses were performed in the 1970s, and have revealed no adverse effects. To supplement the minimal data on EMP effects on animals, recent literature on the bioeffects of intense, pulsed microwaves was reviewed. Based on an analysis of all of the available information cited above, it is highly unlikely that any detrimental effects on human health or the environment will result from chronic exposures to EMP simulator fields.

A variety of existing and newly proposed safety standards have been developed for radiofrequency EM radiation. Several standards set limits on the peak pulsed field strengths that are permissible for human exposure. We believe that conforming with these exposure limits will adequately protect workers at EMP simulator sites, the surrounding communities, and the environment.

Despite the data cited above, there are gaps in our knowledge of the effects of chronic exposures to EMP fields. Several methodological flaws exist in virtually all studies conducted to date of the biological effects of EMP exposures of laboratory animals. Therefore, we believe that additional research of the biological effects of EMP exposures should be performed using exposure methods that induce peak, transient electric fields in the animals' bodies that are equivalent to those induced in human beings who are exposed to EMP simulator emissions.

This statement was developed by the Committee on Man and Radiation of the United States Activities Board of The Institute of

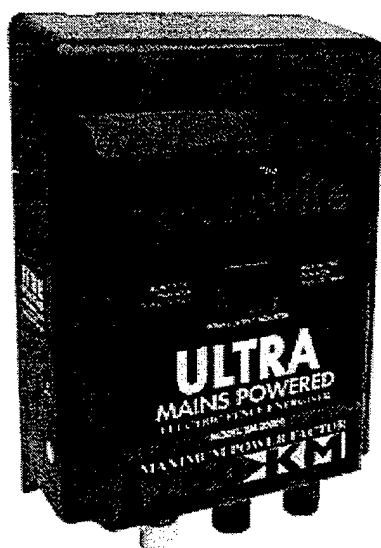
## **Section A-7: Shock of Death- Electricity**



# Energizer - AC Systems

## SM20001

*For use under the most testing conditions with a capacity to maintain high voltage on long fence lines even when subjected to leakage from vegetation. Ideal where land owners are restricted to using one energiser through location of power supply or lay out of farm*



### SPECIFICATIONS:

Power source: 110V - 120V AC  
 Low energy consumption of 14 - 28 Watts  
 Maximum pulse output energy 20J  
 Maximum pulse stored energy 28J

### FEATURES:

- Fence Load Indicators show when the energiser is operating at its maximum capacity.
- Power Output Indicator flashes when energiser is successfully powering the main fence terminal.
- Dual Output Terminals - HIGH for normal conditions and LOW for when full power is not required.
- Temperature Control of Pulse Speed to reduce component failure through heat stress.
- Overpulsing Safety Shutdown Circuitry.
- 'Power On' neon indicator.
- Radio Frequency Interference suppression circuitry.
- Modular Construction for ease of servicing.
- Complies with International Safety Standards.
- 24 months warranty.

[Kiwi Home Page](#)  
[Contact Kiwi](#)

[Product Catalog](#)

[Kiwi Home Page](#) | [Product Catalog](#) | [Contact Kiwi](#)  
[AC Systems](#) | [12V Systems](#) | [Portable Systems](#) | [Accessories](#)

### SM 20001

12 Miles of Overgrown Cattle Fence or 120 Miles of Wire

This top of the line Ultra Power energizer is for use on large farms with long overgrown fences. It will operate about 4 to 5 miles of overgrown sheep, hog, or wildlife fence. Features power, pulse and fence lights, safety circuits, 25 watts 220-240v input, and 18.2/26.0j max output/stored energy.

Comments or Suggestions E-mail: [Peter.Wall@m.cc.utah.edu](mailto:Peter.Wall@m.cc.utah.edu)



## ELECTRIC SHOCK

- [Homepage](#)

Unlike many other hazards which can be seen or heard, there is no advance warning of danger from electricity; and electricity can kill - an average of one in thirty of all electrical accidents are fatal.

Electric shock is a major hazard. The severity of the shock will depend on the level of the current and the length of time it is in contact with the body. At very low levels of current the effect may be only an unpleasant tingling sensation, but this may be enough to cause a man to lose his balance and fall. Higher levels of shock can cause fibrillation of the heart which is almost always fatal. Electric shock can also cause burning of the skin at the point of contact.



Current regions for a.c. 50-60Hz current path longitudinal

Current mA , rms	Length of time current flows	Physiological effects on human beings.
0-1	Not critical	Region up to threshold of p no signs of electrificat
1-15	Not critical	Region up to threshold of c Independent loosening of t from around objects no l Also strong, partly pain on the muscles in finger
15-30	Minutes	Cramplike, pulling together arms, breathing difficul of tolerance.
30-50	Seconds to minutes	Strong cramp effects and lo consciousness. With long ti part of the range, heart ir fibrillation may occur.

50-5	Less than one Heart period.	No fibrillation. Strong sh
	More than one heart period.	Fibrillation. Start of electrification relative period not relevant. Lo consciousness. Current
Over	Less than one heart period	Fibrillation. Start of the e relative to the heart perio Fibrillation during the vul consciousness. Current mark
	More than one heart period	Reversible stopping of the Region of electrical def Loss of consciousness. Burns.

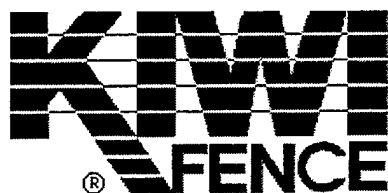
## NOTES

1. Fibrillation - Ventricular.  
Fibrillation, a condition from which it is thought most electrical fatalities occur. This is caused by the passage through the heart of current which disturbs the regular electrical impulses within the heart itself. This results in an oscillating condition rather than the normal regular beating. Blood flow is thus impaired and death follows from lack of oxygen to the brain.
2. Heart period is approximately 750 milliseconds.



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Last updated 09 February 1996 18:56:23



# Energizer Specifications

Model	Input	No Load	Medium	High	Ext. High	Stored Energy	Joule Rating	Mileage of Wire	Ground Rods Required	Avg. Opr. Cost Year
SM 20,000	230 V.AC 25 Watt 60 Hz	7800	7100	4400	3000	28.0	18.2 at 100 ohms	120	12 x 8'	\$13.15
SM 9,800	115 V.AC 10 Watt 60 Hz	7800	6300	3200	2100	14.0	9.4 at 100 ohms	70	7 x 8'	\$7.90
SM 5800	115 V.AC 10 Watt 60 Hz	7500	5800	2800	1650	7.5	5.3 at 100 ohms	40	4 x 8'	\$5.25
SM 2400	115 V.AC 3.5 Watt 60 Hz	7000	3400	1400	800	4.0	2.4 at 350 ohms	20	2 x 8'	\$1.85
SM 1200	115 V.AC 1.7 Watt 60 Hz	7000	3900	2400	900	1.5	1.15 at 400 ohms	10	1 x 8'	\$0.90
SB 5000	12 V.DC Battery	6000	3400	1500	900	7	5	40	4 x 8'	
SB 1500	12 V.DC Battery	5000	3200	1300	700	2	1.5	15	1 x 8' 1 x 3'	
SB 1000	12 V.DC Battery	4200	3000	1100	600	1.3	1.0	6-8	1 x 8'	
AN 90	12 V.DC or 4 "D" Batteries	4000	2800	1000	500	.12	.16	1-2	One 3' Stake	
AN 45	12 V.DC or 4 "D" Batteries	4000	1800	800	400	.04	.048	1/2	One 3' Stake	

\* The above information is a guide only and outlines the manufactures specifications subject to change without notice. KIWI Fence Systems, Inc. manufactures a complete line of components, tools and equipment for high tensile fencing and trellising. For more information, contact your local KIWI

## **Choosing The Right Electric Fencing System**

Whether you are installing a new system or upgrading an existing one, there are a number of points you should take into consideration:

- Where the system is to be used and the type of land it is to be used on.
- The size of the area you wish to fence.
- The type of stock to be controlled.
- The type of wire you wish to carry the current.
- Efficient installation of wires from the ground.
- The conductivity of the ground on which the system will stand.
- The most effective earth-to-ground system.
- Whether the system is to be permanent or movable.
- The type of insulators you require.
- Types and locations of gateways.
- The type of energizer that will best meet your needs.
- Your ability to install and maintain the system to obtain the maximum performance.
- Conformance with safety requirements and regulations.

The true effectiveness of your electric fence system will depend on the attention you pay to all of these points.

## **Choosing Your Energizer**

Your choice of energizer will depend on:

- Power Source - mains or battery?
- Installation - portable or permanent?
- How much power (or joules) that you need. This is determined by:
  1. Area involved.
  2. Distance to extremity of the farm.
  3. Total length of electrified wire - multi or single wire.
  4. Amount of seasonal weed or grass growth affecting the fence line.
  5. Minimum voltage requirement for the type of animal to be controlled.

## **Two Important Points To Note:**

### **1. Output Joules v. Stored Joules.**

PEL measures the power of its energizers in terms of output joules. *Output joules* is the energy available on the fence to power the fence line. It's the energy that provides the shock that stops the stock. In contrast, *stored joules* is the maximum energy the energizer can store internally. When stored energy is released to the fence it decreases by about a third to a half depending on the conditions. Hence quoting stored joules is misleading.

**To get a simple and accurate measure of the power of an energizer always ask the salesperson to quote output joules when comparing brands.**

**2. Distance of Wire.**

Output joules indicates the distance of wire an energizer will power. The higher the joules, the greater the distance. Distance can only be measured in terms of a single strand of wire. For multi-wire fences, divide the length of fence by the number of hot wires.

PEL manufactures a range of advanced, modular design energizers with an energy output to suit every farming situation.

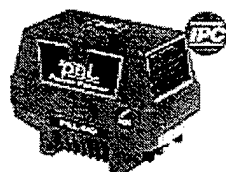
**Two important selection tips:**

1. It is advisable to allow more energy capacity than may be required initially. This will maximize performance in the event of fence defects or future extensions of the fence system.
2. Where mains power is available, mains type energizers are always recommended for their convenience, low maintenance and higher capacity.

**Once you have installed the PEL system that most effectively meets your requirements you will be assured of PEL's ongoing service and backup.**

## Mains High Power Energizers

*PEL's Series 6 Energizers are more efficient because of their advanced circuitry which means more power is available on the fence to keep stock safe and your fence effective even under extreme conditions.*



**PEL 628 Powers up to 280 km of wire.**

**PEL 618  (110 volt) Powers up to 170 km of wire.**

**PEL 618  (240 volt) Powers up to 170 km of wire.**

**PEL 610  Powers up to 100 km of wire.**

**PEL 609  Powers up to 100 km of wire.**

**PEL 605 Powers up to 50 km of wire.**

### **Common Features for PEL 628, 610 & 605**

Unique Monitor Warning Lamps indicate power loss due to an earth or fence fault.

Removable Service Modules.

High and low power terminals for selective stock control.

2 year guarantee.

### **Common Features for PEL 618 & 609**

High and low power terminals for selective stock control.

Removable Service Modules.

2 year guarantee.

Monitor Warning Lamps not available.



### **Intelligent Power Control**

The unique Intelligent Power Control (IPC) Computer increases efficiency & reduces costs by continually monitoring operating conditions.

## **Appendix B: Briefing Slides**

# **Area Denial**

**Presented By:**

**Stephen Douglas, Eric Swenson**

**Design Team:**

**Stephen Douglas, Michael Golden, Frank Scherra,  
Eric Swenson, Michael Talbot, Bryan Wiley**

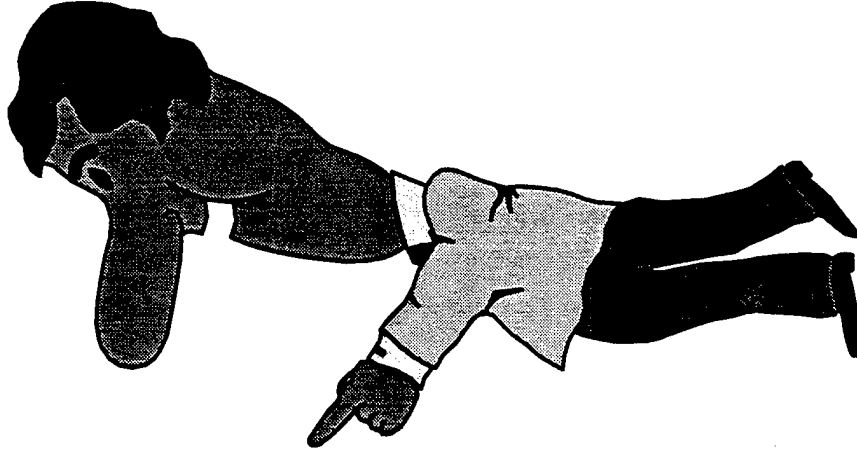
**Advised By:**

**Dr. Don Barr, MAJ Eric Schacht**



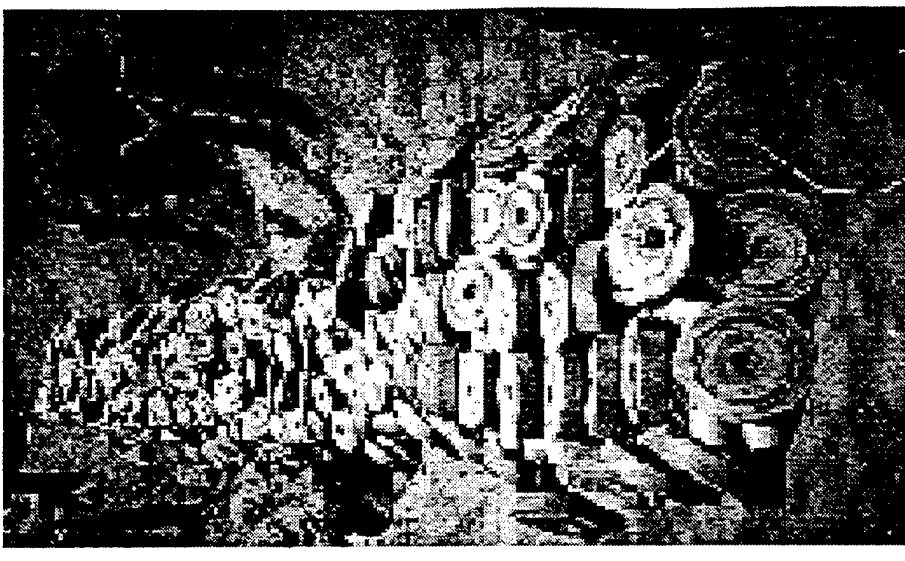
# Agenda

- ◆ Background
- ◆ Primitive and Effective Needs
- ◆ Objectives
- ◆ Measures of Effectiveness
- ◆ Alternatives
- ◆ Feasibility Screening
- ◆ Breakdown of Alternative Designs
- ◆ Modeling
- ◆ Conclusion



# Background

- Landmines effect on U.S. Army Area Denial mission
- U.S.--major producer of land mines over the past 25 years
- 80-110 million landmines strewn across 64 countries
- Kill or maim approximately 25,000 noncombatants per year
- Pressure to sign international landmine ban treaty



# Relevance

- Client: Picatinny Arsenal
- Stakeholders
  - Department of Defense
  - US Army
  - Battlefield Commanders
  - World Population

# **Primitive Need**

Provide a means to deny access of enemy personnel, aerial/land vehicles, and equipment to an area.

# **Effective Need**

Provide a safe and effective means to control the position and movement of the enemy forces.

# Top Level Objectives

- To Control The Position and Movement of the Enemy
  - To Ensure Battlefield Command & Control
  - To Ensure the System is Self-Sufficient
  - To Ensure Compliance of International Laws
  - To Be Cost Effective
  - To Ensure Safety
  - To Be Reliable
  - To Facilitate Easy Integration Into the Military

# Criteria

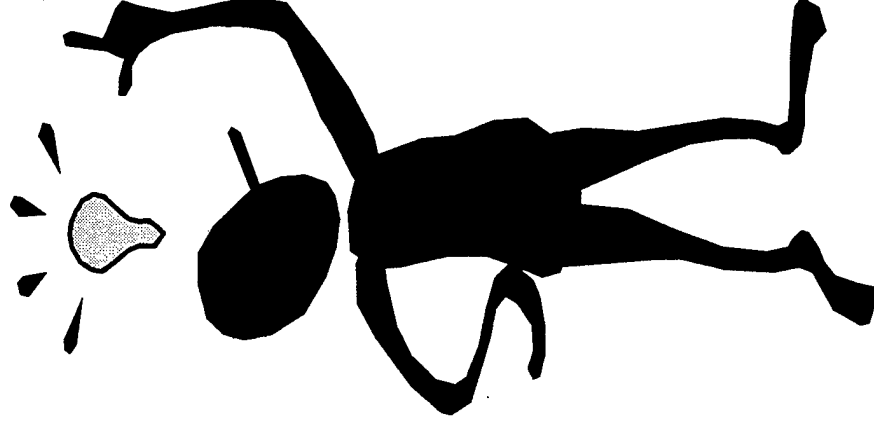
- ◆ Cost to deny area: 10 x 10 km
- ◆ Expected time to field
- ◆ Mean time between failures
- ◆ Size of footprint (km<sup>2</sup>)
- ◆ Life span: at 95% reliability (years)
- ◆ Probability a unit is detected
- ◆ Probability a unit is stopped
- ◆ Penetration distance
- ◆ Percent of all enemy killed

# Components of Area Denial

- Observation
- Delivery
- Deterrent

# Alternatives

- Robotic Vehicles
- Satellites
- IWAM
- UAV
- EMP
- Electricity (discontinued)
- Chemicals (discontinued)





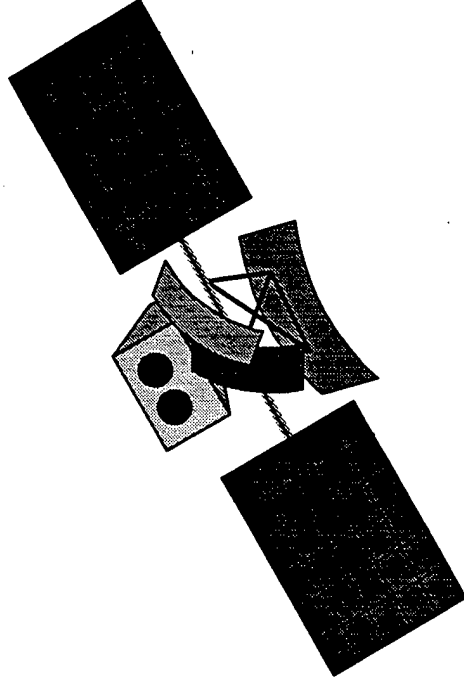
# Robotic Sensor and Attack Vehicle

- GPS, laser range finder, and video monitors for target identification
- Operate independently or remotely controlled (man-in-loop)
- Seismic and acoustic sensors
  - Limited firing capabilities
  - Communicate with an indirect fire center
- Camouflage itself or dig itself in
- Self-destruct function
- Reusable and upgradable



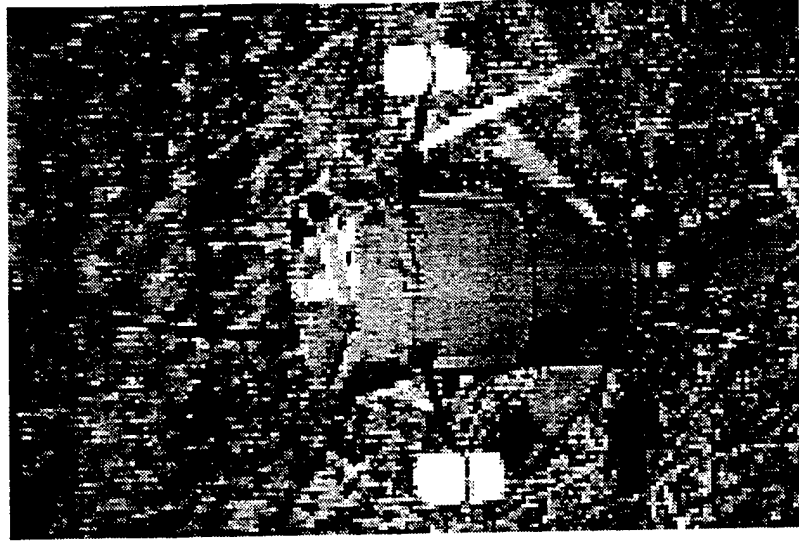
# Satellite ~ Death from Above

- Bands of satellite coverage
- US Satellites: SIS, Spyglass, and Worldview
- Engaging decision made by a man-in-the-loop
- Relay real time information
- Signal to indirect fire site



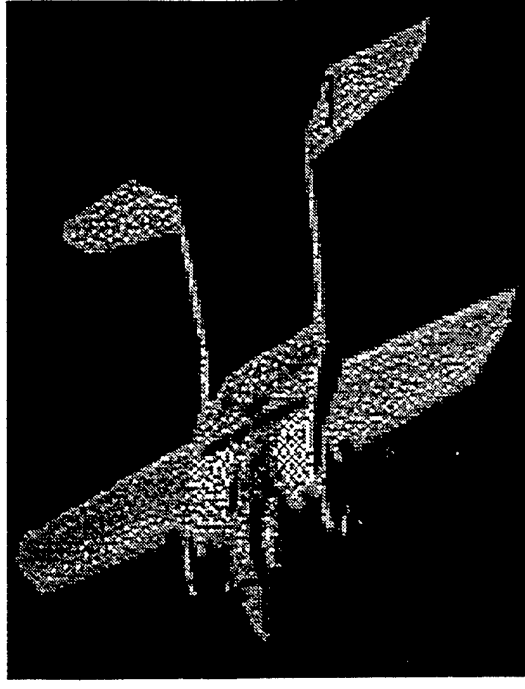
# IWAM ~ Network of Destruction

- Network of WAMs
- GPS, laser ranging, seismic and acoustic sensors
- Activate when sensors detect intruder
- Identifies friend or foe
- Monitor center reviews information
- Fires round or relays enemy location to indirect fire center
- Proximity sensor to prevent enemy tampering



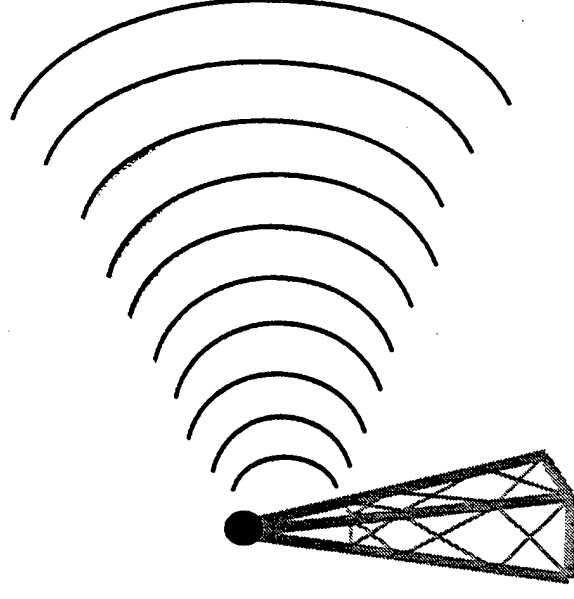
# UAV ~ Angel of Death

- GPS, video, and laser ranging
- Real-time surveillance of enemy
- Controlled by monitor station
- Man-in-the-loop security guard
- Loaded with various weapons  
based on expected enemy force
- Can attack or relay location of  
enemy to indirect fire center



# **Electro-Magnetic Pulse (EMP)**

- Direct-indirect applications
- Non-lethal technology
  - Disable enemy aircraft, vehicles or vessels
- Emplaced by UAV's and artillery
- Variable Footprint
  - High or low altitude detonation
- Disrupt electronic equipment
  - Navigational devices
  - Electronic ignitions
- Silent combat multiplier
  - Disable or delay the enemy mission



# Feasibility Screening

- Screening Constraints
  - Cost, Safety, Humane, Failure Rate, Radius of Kill, Environmental Concerns, Technology Available, Research Available
- Screened Alternatives
  - Electricity
  - Chemical

# Comparing the Alternatives

- Simulation
  - Self developed Visual Basic modules in Excel
- Input weapon parameters
  - Lethal radius
  - Size of system
  - Type of system
  - Carlton model: Probability of hit
- Analysis measures of effectiveness

# Modeling

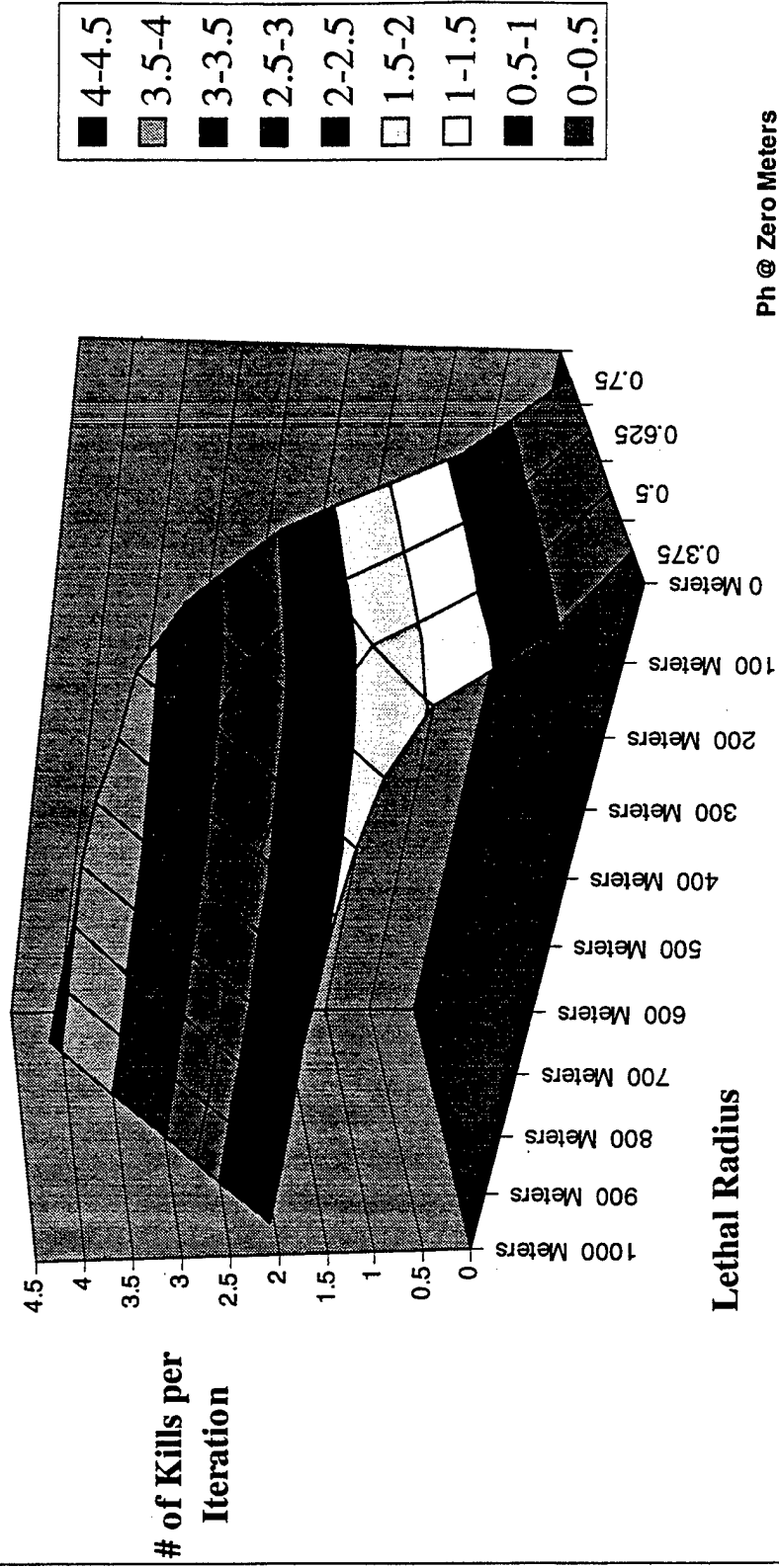
- Measures of Effectiveness
  - Average number of enemy killed
  - Percent of all enemy killed
  - Percent denial
  - Average number of hits
  - Percent of enemy units engaged
- Analytical Modeling
  - Poisson process and time delays
  - MOE's
    - Average Penetration Distance
    - Average time to delay



# Modeling Output for EMP

Average # of Kills per Iteration w/ $P_{klh} = .4$

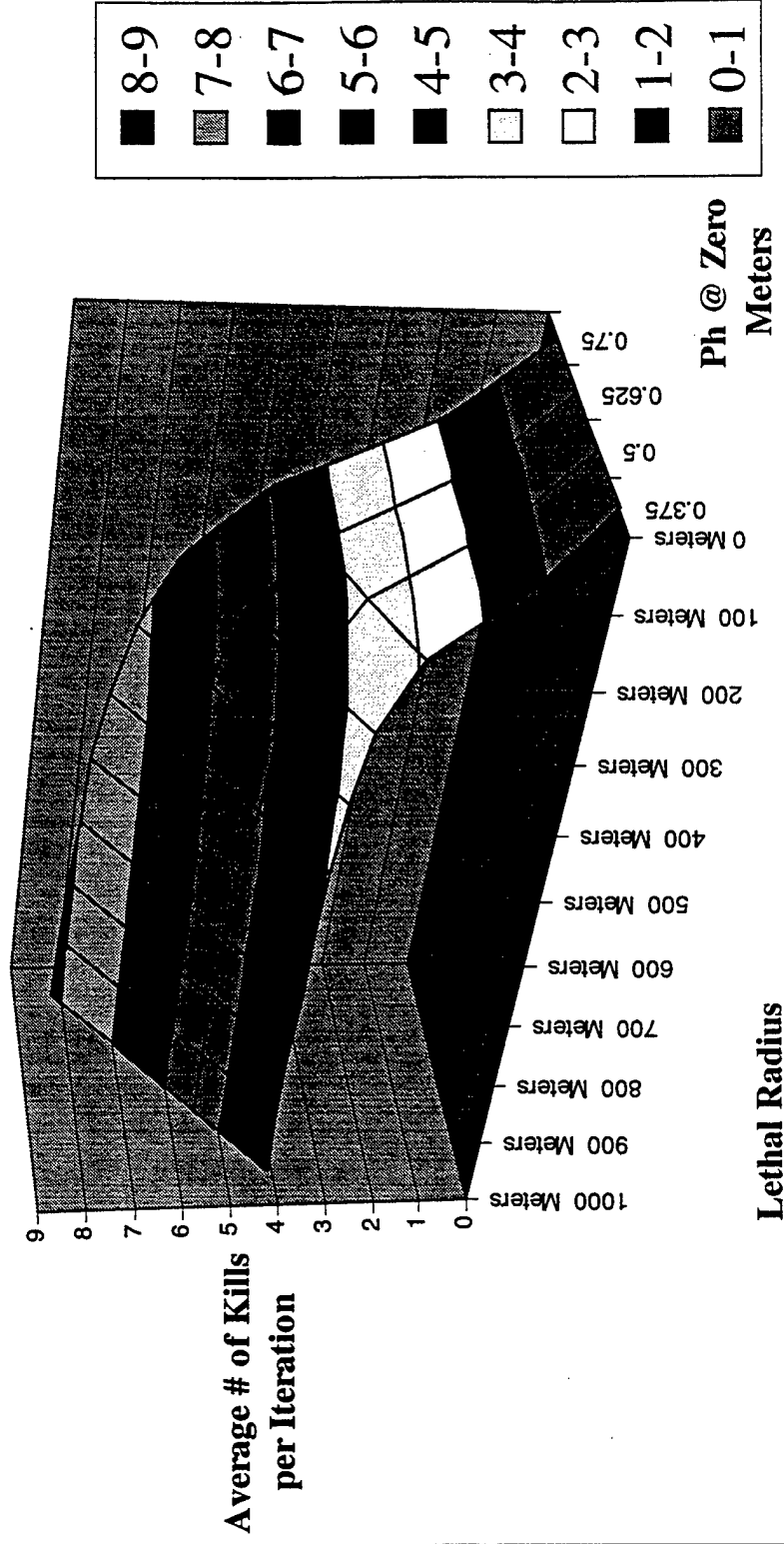
$P_h$  @ Lethal Radius = 0.1



# Modeling Analysis

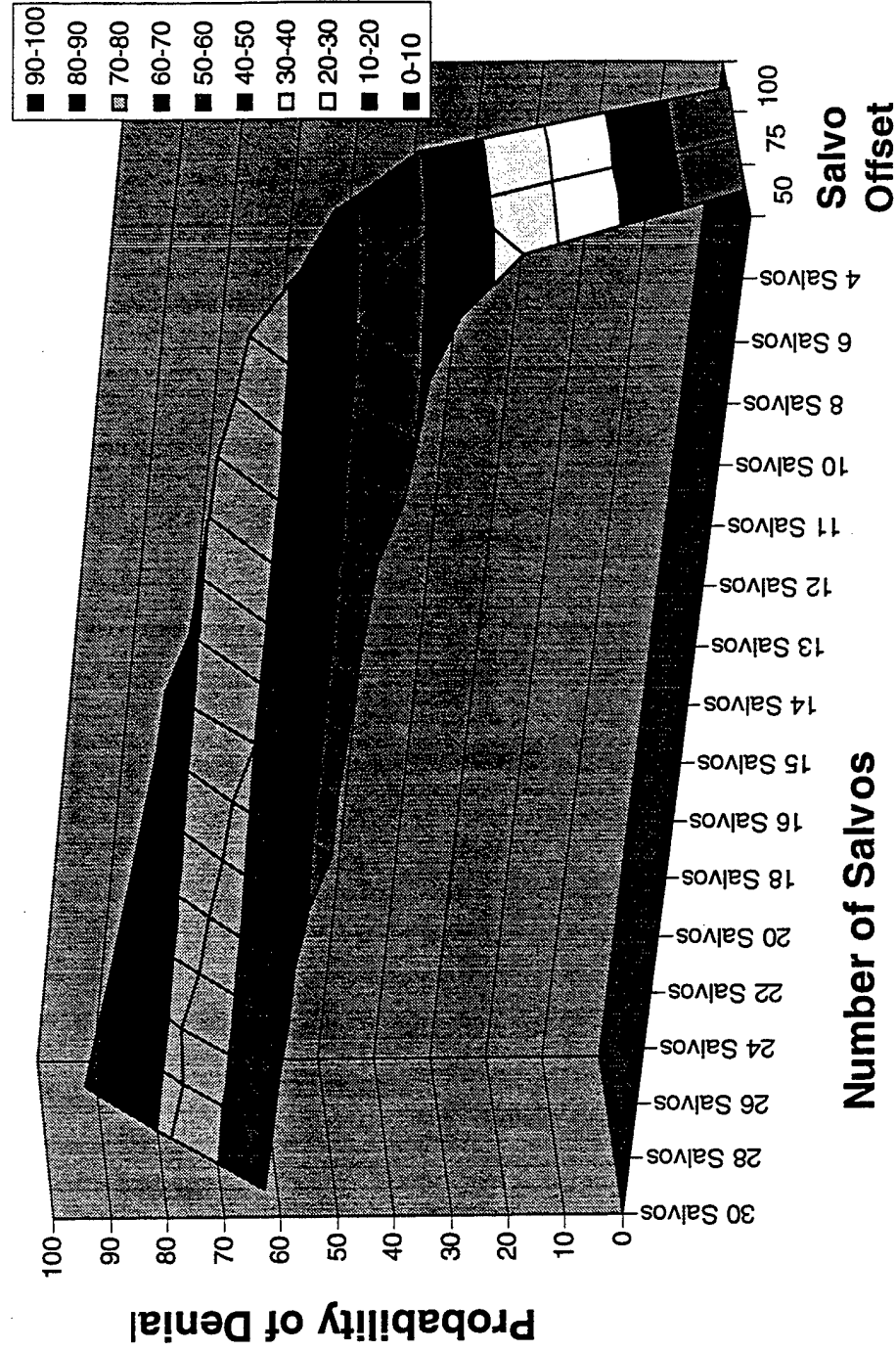
Average # of Kills Per Iteration w/ $P_{k|h} = .8$

$P_h$  @ Lethal Radius = 0.1



# Modeling Output for Conventional Artillery

Probability of Denial Per Iteration w/(Pklh = .2)l(Ph = .65)



# Analysis

- Sensitivity of performance with system cost
- Total utility comparison
- Conclusions
  - number of rounds and not cost effective
  - Local Indirect fire
    - Local denial systems provide a physically present threat/deterrent
    - IWAM, Robotics
    - Designated rounds increase utility of indirect fire methods
  - EMP has potential
  - One round v. multiple rounds

# Recommendation

- Short Run
  - IWAM/Robotic Vehicle
    - Existing technology
    - Potential to designate targets
    - Physical presence/deterrent
- Long Run
  - EMP
    - Cost and denial effective
    - “Non-lethal”
    - No enduring effects to civilians

# References

- Carlton Function: Notes on Firing Theory
  - Naval Postgraduate School, Monterey, California
- EMP
  - Research cited from Carlo Kopp
    - Australian scientist, Professor at Monash University, 1996

# Questions???



## **Appendix C: Objectives Outline**



## Appendix C: Objectives Outline

**EFFECTIVE NEED: To Provide a Safe and Effective Means to Control the Position and Movement of the Enemy Forces**.135 (+8%) A. To Ensure Battlefield Command And Control.2 1) To Increase awareness of where devices operate and their status1 a) Maximize effective control distance

Criterion:

Name: Control DistanceUnit of Measure: Miles.2 2) To ensure commanders' ability to turn on/off1 a) Increase ability or ease to arm or disarm the unit

Criterion:

Name: Time to Arm or DisarmUnit of Measure: Minutes.2 3) Increase number of targets able to be identified1 a) To maximize ability to identify targets

Criterion:

Name: Targets IdentifiedUnit of Measure: Number.4 4) To increase friendly control1 a) Maximize the ability to continuously program friendly or foe soldiers and new equipment

Criterion:

Name: Time to programUnit of Measure: Minutes.13 (+ 4%) B. To Ensure The System Is Self-Sufficient (Smart).2 1) To maximize the distance needed to acquire targets

Criterion:

Name: Distance to acquire objectUnit of Measure: Feet.2 2) To minimize the time to acquire to targets

Criterion:

Name: Time to acquire an objectUnit of Measure: Minutes.6 3) To decrease the human intervention required per unit1 a) To minimize the number of components to be serviced

Criterion:

Name: Average time to be servicedUnit of Measure: Minutes.1275 (+ 2%) C. To Ensure Compliance of International Laws1 1) To increase the length of the systems legality

- 1 a) To maximize the probability that there are no foreseeable measures to terminate the project

*Criterion:*

Name: Years of legality

Unit of Measure: Years

.1225 (- 4%) D. To Be Versatile

- .125 1) To increase adaptability to different terrain areas

*Criterion:*

Name: Number of shapes the system can deny

Unit of Measure: Number of shapes

- .325 2) To decrease deployment and recovery time

- .4 a) Minimize the amount of reusable parts of the unit

*Criterion:*

Name: Number of reusable parts in device

Unit of Measure: Number of parts

- .6 b) Minimize weight of the system

*Criterion:*

Name: Weight of system

Unit of Measure: Pounds

- .25 3) To increase adaptability against different types of forces

- 1 a) Maximize different types of equipment it is able to deter against

*Criterion:*

Name: Number of functions performed; armor-piercing, anti-tank, anti-vehicle, anti-aerial

Unit of Measure: Number of functions

- .125 4) To increase ease of transporting

- 1 a) Maximize ability for soldier or soldiers to affix device or parts to the person

*Criterion:*

Name: Ease and comfort of affixing device

Unit of Measure: number of attachment sites

- .125 5) To maximize endurance of system in all weather conditions

*Criterion:*

Name: Endurance to weather and climate

Unit of Measure: Time

.125 (- 2%) E) To Be Reliable

- .25 1) To increase the amount of time the system can be stored

- 1 a) To maximize shelf life

*Criterion:*

Name: Years until expiration

Unit of Measure: Years

- .75 2) To minimize the probability of system failure

*Criterion:*

Name: Mean time between failures

Unit of Measure: Days

.1175 (- 8%) F) To Facilitate Easy Integration Into The Military

- .333 1) Maximize the ability to integrate with existing technology

*Criterion:*

Name: Integrate?

Unit of Measure: Yes / No

.167 2) To minimize training time required

Criterion:

Name: Training time per unit on system

Unit of Measure: Days

.167 3) To decrease fielding time

Criterion:

Name: Time to field

Unit of Measure: Months

.333 4) To decrease enemy ability to defeat the system

1 a) Maximize encryption ability

Criterion:

Name: Secure system

Unit of Measure: Yes / No

.120 (- 6%) G To Be Cost Effective

.307 1) To decrease deployment costs

.8 a) To minimize transportation costs

Criterion:

Name: Transportation Cost

Unit of Measure: Dollars/mile

.2 b) To minimize training costs

Criterion:

Name: Training Cost

Unit of Measure: Dollars/unit

.692 2) To minimize clean up costs

Criterion:

Name: Clean up cost

Unit of Measure: Dollars/system

.1325 (+ 6%) H To Ensure Safety

.9 1) To decrease environmental impact

1 a) To minimize long-term terrain damage

Criterion:

Name: Time to re-inhabit

Unit of Measure: Years

.1 2) To increase user safety

.3 a) To maximize safe transportation

Criterion:

Name: Probability of detonation during transportation

Unit of Measure: Probability

.7 b) To maximize the safe emplacements

Criterion:

Name: Probably of malfunction in employment

Unit of Measure: Probability

## **Appendix D: Input Data Requirements for Alternative Modeling**

## Appendix D: Input Data Requirements for Alternative Modeling

Area-Dimensional Input Data

Engagement Method:

Mines or Artillery:

Number of Iterations:

Number of Mines:

Field Artillery Input Data:

Salvo Offset:

X Direction:

Y Direction:

Dispersion from Mean Point of Impact:

X Direction:

Y Direction:

Probability of Hit @ Zero Miss Distance:

Probability of Hit @ Lethal Radius:

Probability of Kill Given Hit:

Lethal Radius (m):

Number of Enemy Entities Attacking:

Number of Salvos Per Engagement:

Number of Tubes (Rounds per Salvo):

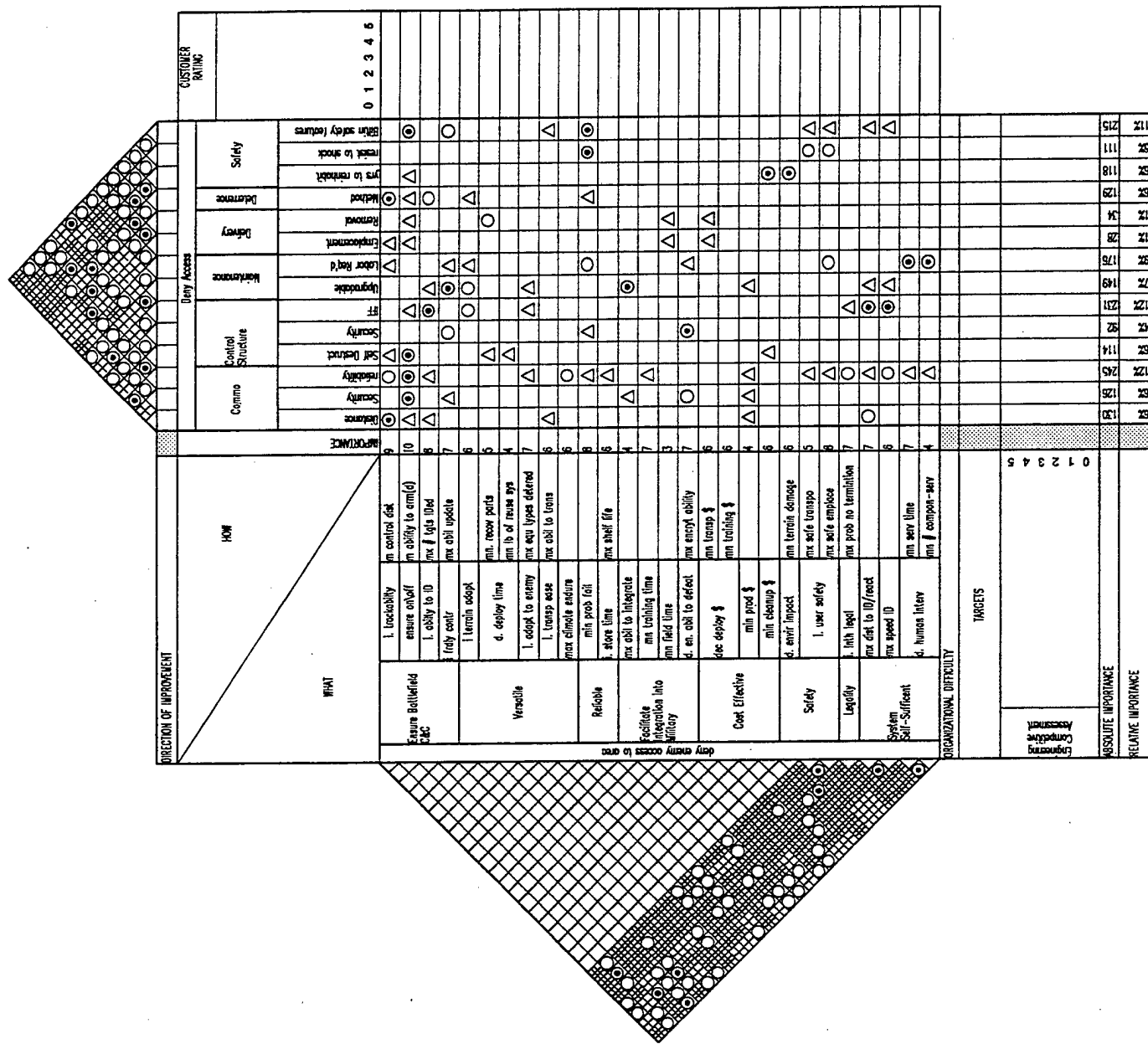
Kill Threshold (Enemy Stops):

Area Dimensions:

Height (m):

Width (m):

## **Appendix E: House of Quality**

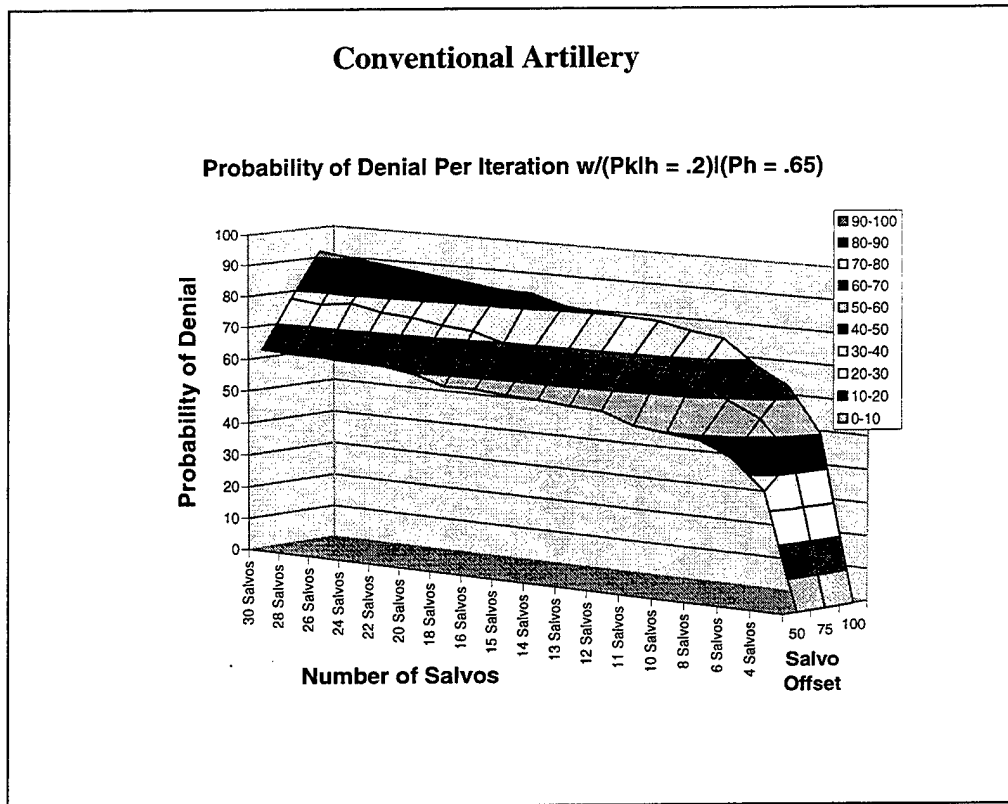


ROOF	MATRIX	WEIGHTS	ARROWS
Strong Pos	Strong	9	Maximum
Positive	Medium	3	Minimum
Negative	Weak	1	Neutral
Strong Neg	Strong Neg		

## **Appendix F: Surface Plots for Alternative Modeling**

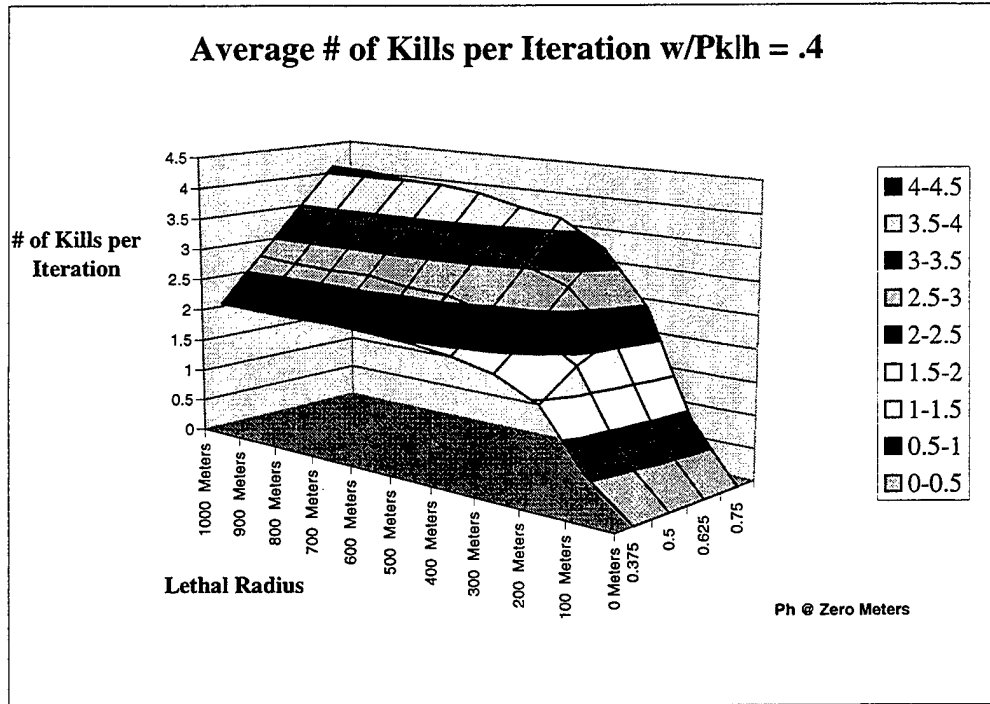


The first surface plot is from Conventional Artillery with a probability of kill given hit of .2. The second is from EMP with a probability of kill given hit of .4.



To get a probability of hit greater than 80% for the conventional mines, the number of salvos must be large and the salvo dispersion must be near 100 meters.

## EMP Alternative



To achieve 80% or greater than two denials with EMP, the probability of hit at zero meters can .375 and the lethal radius can be approximately 600 meters. At the worst case scenario, a low probability of hit at zero meters and a low radius of kill, EMP achieves the desired effect with just one round.

## **Appendix G: Client Brief Critique**

## **Client Brief Critique**

- IWAM's, Robotic vehicles, or UAV's that can launch an EMP round have potential.
- Using already flying UAV's to attack targets based on Satellite observation.
- It may be possible to use EMP with a UAV that would release and designate rounds to military targets.
- He also indicated that it may be possible to put EMP in a 155 round.
- The client was interested in UAV's and satellites, however, did not feel they are as vital as EMP, IWAM's. or Robotics.
- Cost is not an issue.
- Client concerned with effective system.
- The urban denial problem is something that we did not consider, however, is going to be prevalent in future conflicts.
- He also did not seem to mention anything about AP mines.
- The client's main concern is with vehicular denials.
- The client seemed to want additional work done on the project.
- The army after next is having trouble heading armor columns off before they get to a city.
- EMP is a viable alternative since it is non lethal and can be employed early in the conflict when casualties are not welcomed, etc.
- Look at using conventional IWAM's with EMP. IWAM's and have some sort of man in the loop to determine if the conventional round or EMP round fires.
- Is it possible to produce some sort of counter pulse to retard the EMP and avoid damage?
- The Army is working on new DIS entities for future simulations.